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BRUCE NGS 'A'
EMERGENCY COOLANT INJECTION RECOVERY PUMPSETS
VIBRATION ANALYSIS

Report No 87-301-K

N. Jagan, Engineer
F. Perricone, Unit Head
W. Morgan, Technologist
Plant Equipment Dynamics Section
Mechanical Research Department

ABSTRACT

Detuning of the four ECI Recovery Pumpset motors at 19.75 Hz (operating speed) in the East-West direction with undamped dynamic vibration absorbers significantly reduced the vibration amplitude at 1 x RPM frequency to an acceptable level on all motors. With the motor structural natural frequency at 19.75 Hz in the East-West direction detuned, the North-South direction is a more appropriate direction for vibration monitoring than is the East-West (presently done). Repositioning of the radially oriented velocity transducer at the top of the motors to the tangential direction (predominantly North-South) is recommended.

job	file	date	report no.
27-139-552	825.4	January 21, 1988	87-301-K

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EXECUTIVE SUMMARY

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In December 1985, a vibration analysis of the Emergency Coolant Injection Recovery Pumpsets #21 - #24 indicated that high vibration levels at 1 x RPM measured on the motors were primarily due to a motor structural natural frequency (in the East-West direction) near the running speed (19.75 Hz) amplifying the motor structure response.

In June 1987, the implementation of an undamped dynamic vibration absorber was evaluated on each of the four pumpset motors. The absorbers proved effective in detuning the motors' structure at 19.75 Hz, significantly reducing the motor 1 x RPM vibration component in the East-West direction to an acceptable level. An analysis of the absorber springs indicated that failure due to fatigue during the lifetime of the pumpsets is unlikely.

With the motor structural natural frequency at 19.75 Hz in the East-West direction detuned, the North-South direction is a more appropriate direction for vibration monitoring than is the East-West (presently done). Repositioning of the radially oriented velocity transducer at the top of the motors to the tangential direction (predominantly North-South) is recommended.

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To: Mr. B.R. Churchill
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BRUCE NGS 'A'
EMERGENCY COOLANT INJECTION RECOVERY PUMPSETS
VIBRATION ANALYSIS

1.0 INTRODUCTION

In December 1985, a vibration analysis of the four Emergency Coolant Injection Recovery Pumpsets indicated that high vibration levels at 1 x RPM measured on the motors were primarily due to a motor structural natural frequency near the operating speed amplifying vibration. It was recommended that an undamped dynamic vibration absorber be installed to detune the motor structural natural frequency thereby reducing the 1 x RPM vibration.

In June 1987, the four absorbers were installed, tuned and tested. The performance of the absorbers in reducing the vibration levels are discussed in this report.

Each vertical pumpset consists of a two-stage Bingham-Willamette Pump with a rated capacity of 606.7 L/s (8000 IGPM) and a head of 67 m (250 ft); and a Canadian General Electric Induction Motor rated at 600 kW (800 HP) at 1183 RPM.

2.0 TEST METHOD, INSTRUMENTATION AND MEASUREMENTS

2.1 Test Method

The general pumpset arrangement, measurement locations and directions, as well as the identification used for the report, are shown in Figure 1. Vibration measurements were taken at the top and bottom of the motor, and at the pump stool in the East-West (E-W), North-South (N-S) and axial directions during pumpset operation. The E-W direction is referred to as the "soft direction" (ie, perpendicular to the discharge line), and the N-S direction referred to as the "hard direction" (ie, parallel to the discharge line).

Vibration measurements were taken with the pumpsets operating on recirculation at a flow rate of approximately 311 L/s (4100 IGPM). This was the maximum flow rate possible for testing purposes. The pumpsets are operated at this flow rate for a few hours once per month (Safety Systems Test). The pumpsets would normally only operate at the design flow rate of 606.7 L/s (8000 IGPM) in the event of a loss-of-coolant accident.

The ECI Recovery Pump characteristic curve is shown in Figure 2.

2.2 Instrumentation

The main components of the instrumentation used in obtaining the measurements are listed in Table 1.

2.3 Measurements

2.3.1 Overall Vibration Levels

The overall velocity levels were determined from accelerometer (Bruel & Kjaer Model 4368) signals which were integrated to velocity and then analyzed with a Bently Nevada Digital Vector Filter (DVF 2). The DVF 2 digital vector filter is a peak reading instrument.

Overall velocity levels were measured before and after installation of the dynamic vibration absorbers.

2.3.2 Velocity Spectra

Velocity spectra were generated by analyzing the accelerometer signals (integrated once) with an Ono Sokki CF 920 dual channel Fast Fourier Transform (FFT) analyzer. Hard copies of the spectra were obtained with a digital plotter (Hewlett-Packard 7470A).

Each velocity spectrum shown in this report is the average of sixteen instantaneous spectra.

2.3.3 Impact Spectra

Motor structural natural frequencies in both the E-W and N-S directions were determined by impact testing. With the pumpsets not running, the motors were excited throughout a range of frequencies (5-100 Hz) with a hammer having an elastomeric tip and instrumented with a force transducer. The input force (hammer) and the motor response (accelerometer signal integrated twice to give displacement) signals were fed simultaneously into the dual channel FFT analyzer which calculated the input and response spectra as well as the compliance transfer function. The validity of the transfer function was checked by the coherence of the input and response signals. A coherence value greater than 0.8

indicates that the response is predominantly due to the input. The ambient noise was reduced by averaging the results of eight impacts.

Impact tests were performed at the top of the motors.

3.0 THE UNDAMPED DYNAMIC VIBRATION ABSORBER

3.1 General Description

The undamped dynamic vibration absorber is a simple spring-mass system as shown in Figure 3. The device operates on the principle that at the design frequency, the motion of the absorber is large and this generates a force which opposes the motion of the structure to which it is attached and reduces the structure's vibration amplitude to near-zero. In effect, the unacceptable vibration level of the structure is removed at the expense of a larger (but acceptable) vibration level of the absorber.

Figure 4 shows the dynamic vibration absorber attached to the top of one of the ECI Recovery Pumpset motors.

3.2 Absorber Mass

The absorber mass was chosen to be 263 kg. This is approximately 9% of the motor dynamic mass as measured near the top of the motor structure. The mass material is lead (in a steel casing).

3.3 Absorber Spring

The absorber spring incorporates a compact hairpin design. Since the spring would experience cyclic strains during pumpset operation, a high strength steel (SPS 245) with good fatigue properties was selected.

The theoretical formulation for the spring stiffness calculation is outlined in Appendix A.

3.4 Absorber Attachment Plate

An annular steel plate (1.5 in. thick) was bolted to the top of the motor at the existing eight bolt locations. The dynamic vibration absorber is attached to this plate using six screws.

4.0 RESULTS AND DISCUSSION

4.1 Motor Structural Natural Frequencies

Impact spectra obtained at the top of the pumpset motors #21, #22, #23 and #24 (E-W and N-S directions), with and without the absorber installed are shown in Figures 5-8, Figures 9-12, Figures 13-15 and Figures 16-19, respectively.

Figures 5,9,13 and 16 show a motor structural natural frequency in the East-West (soft) direction close to the operating speed (19.75 Hz) for the four ECI Recovery Pumpset Motors (without absorber). The high motor casing vibration levels at 1 x RPM in the soft direction (Section 4.2) can be attributed to amplification of the casing response by this structural natural frequency.

A comparison of impact spectra measured on each of the four motor casings (East-West direction) with and without the dynamic vibration absorber installed (Figures 20-23) show that the absorber is effective in detuning the motor structural natural frequency near the operating speed.

4.2 Overall Vibration Levels and Velocity Spectra

The overall vibration velocity levels and the 1 x RPM vibration levels measured on the four pumpsets (Pumpset #21 to Pumpset #24) before and after installation of the dynamic vibration absorber are summarized in Table 2 to Table 5. The corresponding velocity spectra figure numbers are also listed in these tables.

Comparison of the 1 x RPM frequency vibration level on the four pumpset motors in the East-West (soft) direction with and without the absorber, show that the undamped dynamic vibration absorbers are effective in significantly reducing the 1 x RPM (19.75 Hz) vibration to an acceptable level. For example, the 1 x RPM vibration level at the top of the Pumpset #23 motor casing (East-West direction) decreased from 7.15 mm/s to 0.21 mm/s (Table 4).

The reduction in the 1 x RPM frequency component was, in some instances, not accompanied by a significant reduction in the motor casing overall velocity levels. This is due to a high level broadband flow exictation of the motor casing caused by the recirculation operating conditions. When the pumpsets operate at their design conditions, the overall vibration levels are expected to be significantly lower.

4.3 Absorber Spring Fatigue Life Analysis

A strain gauge was attached to the absorber spring of Pumpset #22 absorber to determine the approximate cyclic strain in the spring during pumpset operation. The strain gauge was located on the inside radius of the spring close to the bottom of the curved section (Figure 84) since this would be the region of maximum strain due to bending. The maximum cyclic strain recorded was approximately 20 microstrain peak-peak.

Maximum overall displacement levels were measured on each of the four absorber masses (pumpsets operating) and the corresponding maximum tensile strains in the absorber springs were calculated (Appendix B). For Pumpset #22, a maximum tensile strain of approximately 52 microstrain peak-peak is calculated. The discrepancy between the measured and calculated strains is not

fully understood. For the fatigue life analysis of the absorber springs, outlined in Appendix B, the calculated strain is used since this would yield more conservative results.

The theoretical fatigue life analysis was carried out for the Pumpset #23 absorber spring only since this spring experiences the maximum strain. The results of the analysis indicates that premature failure of the four absorber springs due to fatigue during the lifetime of the pumpsets is not expected.

4.4 Repositioning of Velocity Transducers

For on-line vibration monitoring, two velocity transducers are installed at the top of the ECI Recovery Pumpset motors, one directed radially and the other axially (Figure 85). Provision has also been made for directing the sensitive axis tangentially. In the present mounting configuration, the radial direction is predominantly the soft (East-West) direction; and the tangential direction, the hard (North-South) direction.

As discussed in Sections 4.1 and 4.2, the dynamic vibration absorbers were successful in detuning the motor structural natural frequency near the operating speed in the soft (East-West) direction thereby significantly reducing the 1 x RPM vibration level in this direction. Comparison of the 1 x RPM vibration in the East-West and North-South directions (Tables 2-5) at the top of the motors with absorber installed shows relatively higher levels in the North-South direction. It appears, therefore, that the North-South direction is now a more critical direction for monitoring than is the East-West. It is recommended that the radially oriented velocity transducer be repositioned in the tangential direction on all four motors.

5.0 CONCLUSIONS

5.1 An undamped dynamic vibration absorber installed on each of the four ECI Recovery Pumpset motors was effective in detuning the motor structural natural frequency (East-West direction) near the operating speed. The 1 x RPM vibration component in the East-West direction was reduced to an acceptable level.

5.2 Failure of the absorber springs due to fatigue during the lifetime of the pumpsets (30 years) is not expected.

5.3 With the motor structural natural frequency at 19.75 Hz in the East-West direction detuned, the North-South direction (top of motor) is a more appropriate direction for vibration monitoring than is the East-West (presently done).

6.0 RECOMMENDATION

It is recommended that the radially oriented velocity transducer at the top of the motors be repositioned to the tangential direction (predominantly North-South).

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TABLE 1

INSTRUMENTATION LIST

1.	Accelerometer:	Bruel & Kjaer Model 4368
2.	Charge Amplifier:	Bruel & Kjaer Model 2635
3.	Dual Channel FFT Analyzer:	Ono Sokki CF920
4.	Digital Plotter:	Hewlett-Packard Model 7470A
5.	Oscilloscope:	Tektronix Model 2215
6.	Filter:	Krohn-Hite Model 3343
7.	Vibration Calibrator:	General Radio Model 1557-A
8.	Digital Vector Filter:	Bently Nevada DVF 2
9.	Instrumented Tip Hammer:	PCB Piezotronics Inc. Model 086B50
10.	Visicorder:	Honeywell Model 1858
11.	Strain Gauge Conditioning Amplifier	Vishay Instruments Model 2310

TABLE 2

BRUCE NGS "A" ECI RECOVERY PUMPSET #21
OVERALL AND 1 x RPM VELOCITY VIBRATION LEVELS
(FLOW RATE 311 L/s)

Measurement Location & Direction	Vibration Amplitude					
	Without Absorber			With Absorber		
	Overall (mm/s pk)	1 x RPM (mm/s pk)	Figure No.	Overall (mm/s pk)	1 x RPM (mm/s pk)	Figure No.
Top of Motor Casing E-W	3.3 - 6.5	3.37	24	2.2 - 5.1	0.08	32
Top of Motor Casing N-S	2.3 - 7.0	0.99	25	2.9 - 9.0	1.07	33
Top of Motor Casing Axial	4.6 - 6.0	0.07	26	3.6 - 5.5	0.06	34
Bottom of Motor Casing E-W	2.0 - 3.6	1.99	27	1.4 - 3.0	0.33	35
Bottom of Motor Casing N-S	1.6 - 3.7	0.66	28	2.6 - 5.5	0.43	36
Pump Stool E-W	1.7 - 2.7	1.59	29	1.7 - 2.5	0.44	37
Pump Stool N-S	1.3 - 2.3	0.15	30	1.4 - 2.4	0.15	38
Pump Stool Axial	1.5 - 2.2	0.20	31	1.7 - 2.5	0.06	39

TABLE 3

BRUCE NGS "A" ECI RECOVERY PUMPSET #22
OVERALL AND 1 x RPM VELOCITY VIBRATION LEVELS
(FLOW RATE 311 L/s)

Measurement Location & Direction	Vibration Amplitude					
	Without Absorber			With Absorber		
	Overall (mm/s pk)	1 x RPM (mm/s pk)	Figure No.	Overall (mm/s pk)	1 x RPM (mm/s pk)	Figure No.
Top of Motor Casing E-W	3.6 - 5.2	3.06	40	1.6 - 2.9	0.07	48
Top of Motor Casing N-S	2.6 - 5.0	0.72	41	2.5 - 3.9	0.82	49
Top of Motor Casing Axial	6.0 - 9.0	0.07	42	6.0 - 9.0	0.03	50
Bottom of Motor Casing E-W	2.8 - 3.5	2.74	43	1.4 - 1.8	0.20	51
Bottom of Motor Casing N-S	1.8 - 3.2	0.80	44	1.6 - 3.2	0.50	52
Pump Stool E-W	2.3 - 3.2	2.01	45	1.0 - 1.5	0.30	53
Pump Stool N-S	1.6 - 2.5	0.24	46	1.1 - 1.6	0.13	54
Pump Stool Axial	1.9 - 3.2	0.27	47	1.9 - 2.9	0.05	55

TABLE 4

BRUCE NGS "A" ECI RECOVERY PUMPSET #23
OVERALL AND 1 x RPM VELOCITY VIBRATION LEVELS
(FLOW RATE 311 L/s)

Measurement Location & Direction	Vibration Amplitude					
	Without Absorber			With Absorber		
	Overall (mm/s pk)	1 x RPM (mm/s pk)	Figure No.	Overall (mm/s pk)	1 x RPM (mm/s pk)	Figure No.
Top of Motor Casing E-W	7.0 -13.0	7.15	56	4.0 - 8.1	0.21	60
Top of Motor Casing N-S	4.0 -10.0	1.76	57	5.7 - 9.9	2.14	61
Top of Motor Casing Axial	-	-	-	7.0 - 9.3	0.08	62
Bottom of Motor Casing E-W	3.0 - 6.0	5.14	58	2.2 - 6.0	0.50	63
Bottom of Motor Casing N-S	3.8 - 5.8	0.97	59	3.2 - 5.3	1.17	64
Pump Stool E-W	-	-	-	2.5 - 4.8	0.84	65
Pump Stool N-S	-	-	-	2.5 - 3.0	0.35	66
Pump Stool Axial	-	-	-	2.5 - 3.5	0.11	67

TABLE 5

BRUCE NGS "A" ECI RECOVERY PUMPSET #24
OVERALL AND 1 x RPM VELOCITY VIBRATION LEVELS
(FLOW RATE 311 L/s)

Measurement Location & Direction	Vibration Amplitude					
	Without Absorber			With Absorber		
	Overall (mm/s pk)	1 x RPM (mm/s pk)	Figure No.	Overall (mm/s pk)	1 x RPM (mm/s pk)	Figure No.
Top of Motor Casing E-W	2.9 - 5.2	2.31	68	3.2 - 5.2	0.12	76
Top of Motor Casing N-S	2.7 - 5.0	1.08	69	2.9 - 5.6	1.20	77
Top of Motor Casing Axial	5.7 - 8.9	0.11	70	4.4 - 6.3	0.13	78
Bottom of Motor Casing E-W	1.9 - 2.7	0.76	71	1.5 - 3.6	0.42	79
Bottom of Motor Casing N-S	2.5 - 3.5	0.44	72	2.0 - 3.5	0.47	80
Pump Stool E-W	1.5 - 2.4	0.20	73	1.7 - 3.2	0.44	81
Pump Stool N-S	1.5 - 2.6	0.13	74	1.8 - 2.3	0.15	82
Pump Stool Axial	2.5 - 3.1	0.14	75	1.6 - 3.5	0.02	83

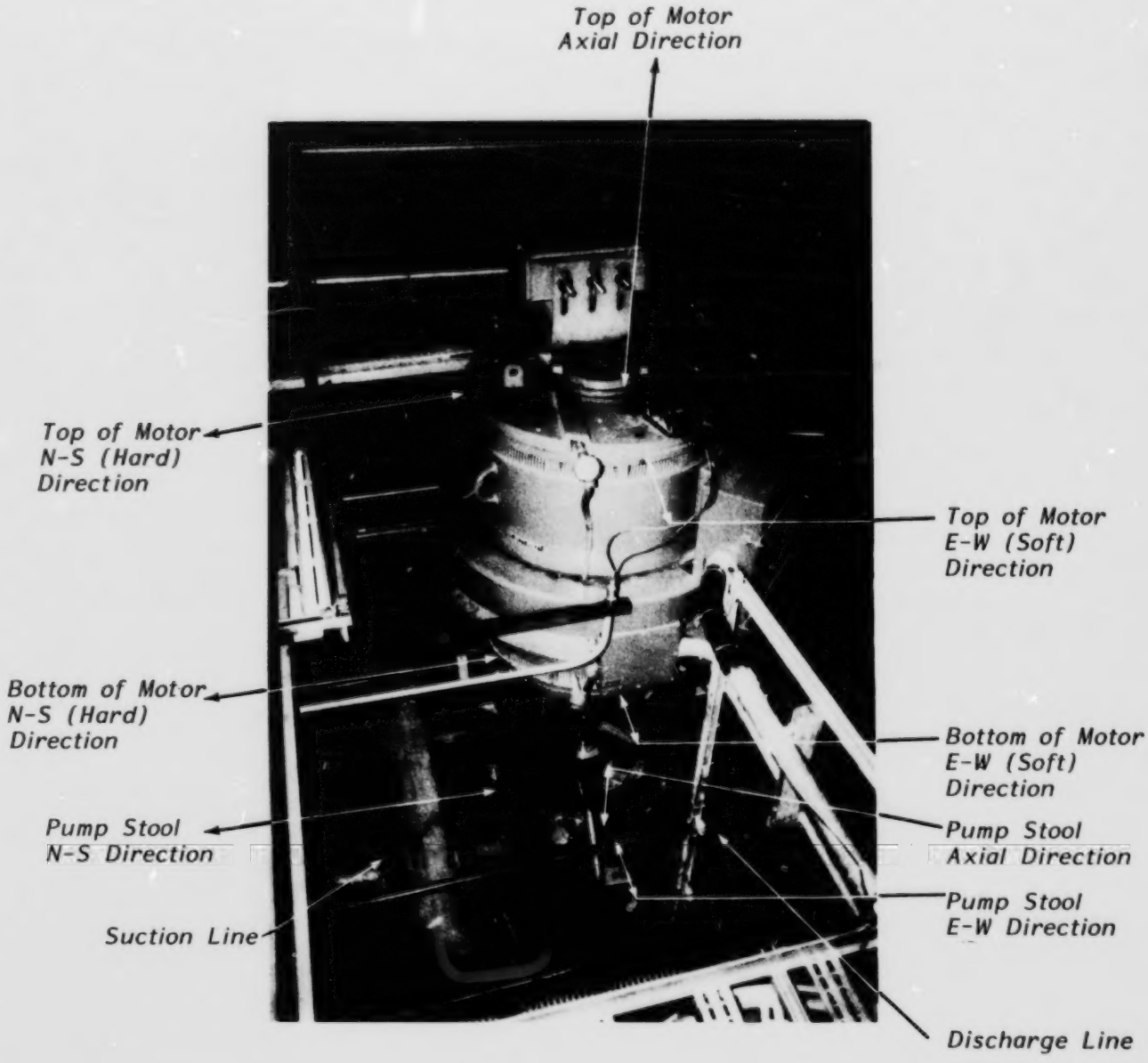

FIGURE 1

ECI RECOVERY PUMPSET MEASUREMENT
LOCATIONS AND DIRECTIONS

176030-RD

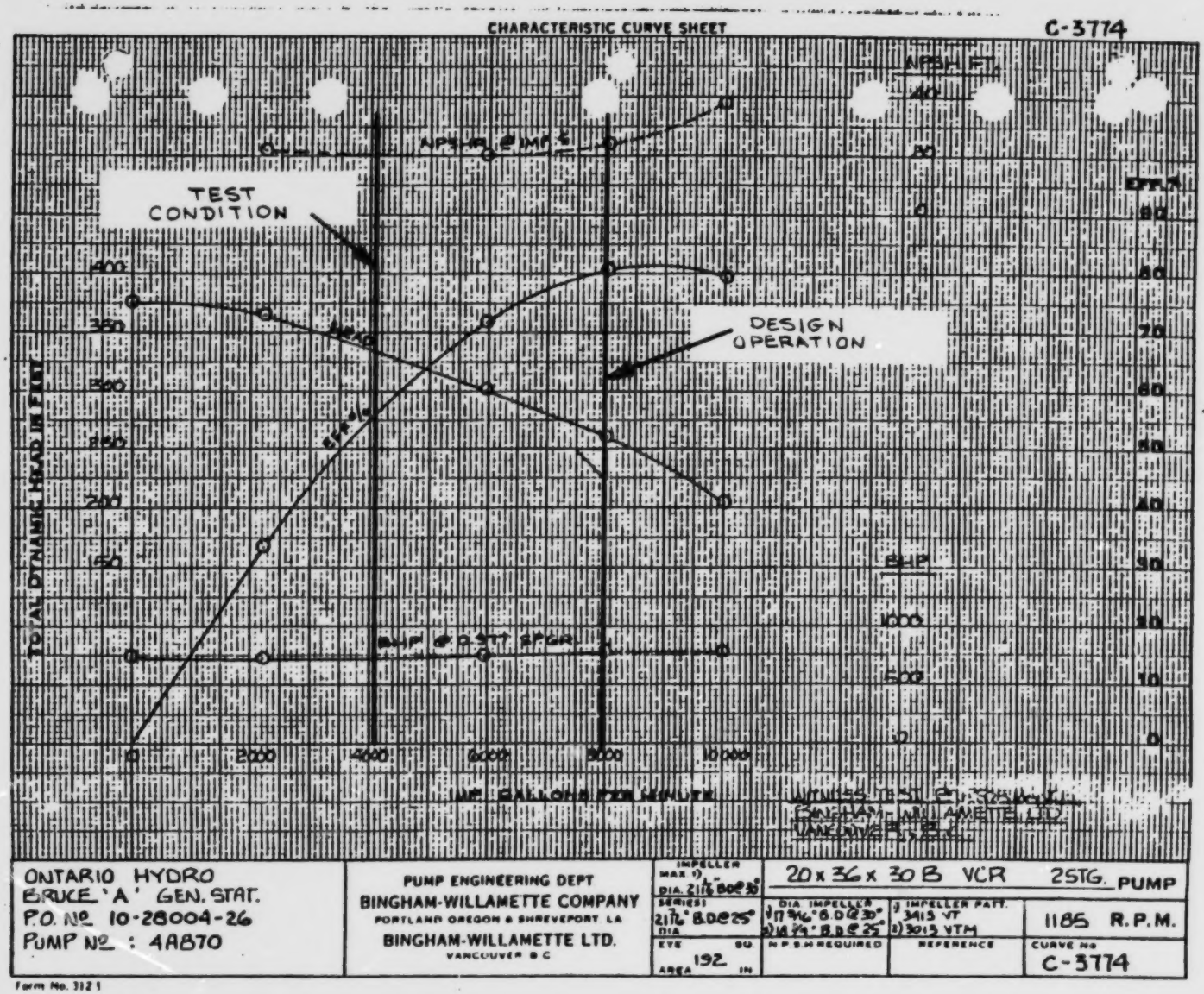

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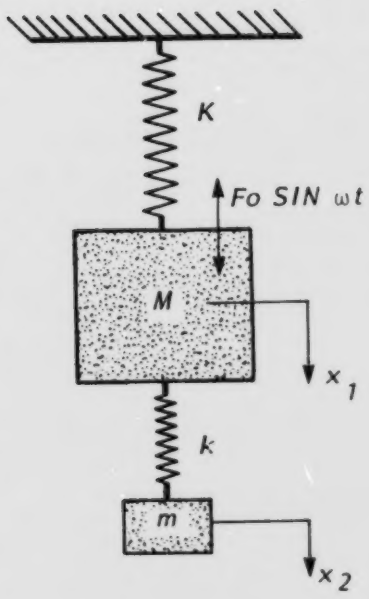
FIGURE 2

BRUCE NGS 'A' ECI RECOVERY PUMP CHARACTERISTIC CURVE



M = Machine Mass
m = Dynamic Absorber Mass
K = Machine Stiffness
k = Dynamic Absorber Stiffness

FIGURE 3

DYNAMIC MODEL OF THE MACHINE-DYNAMIC ABSORBER SYSTEM

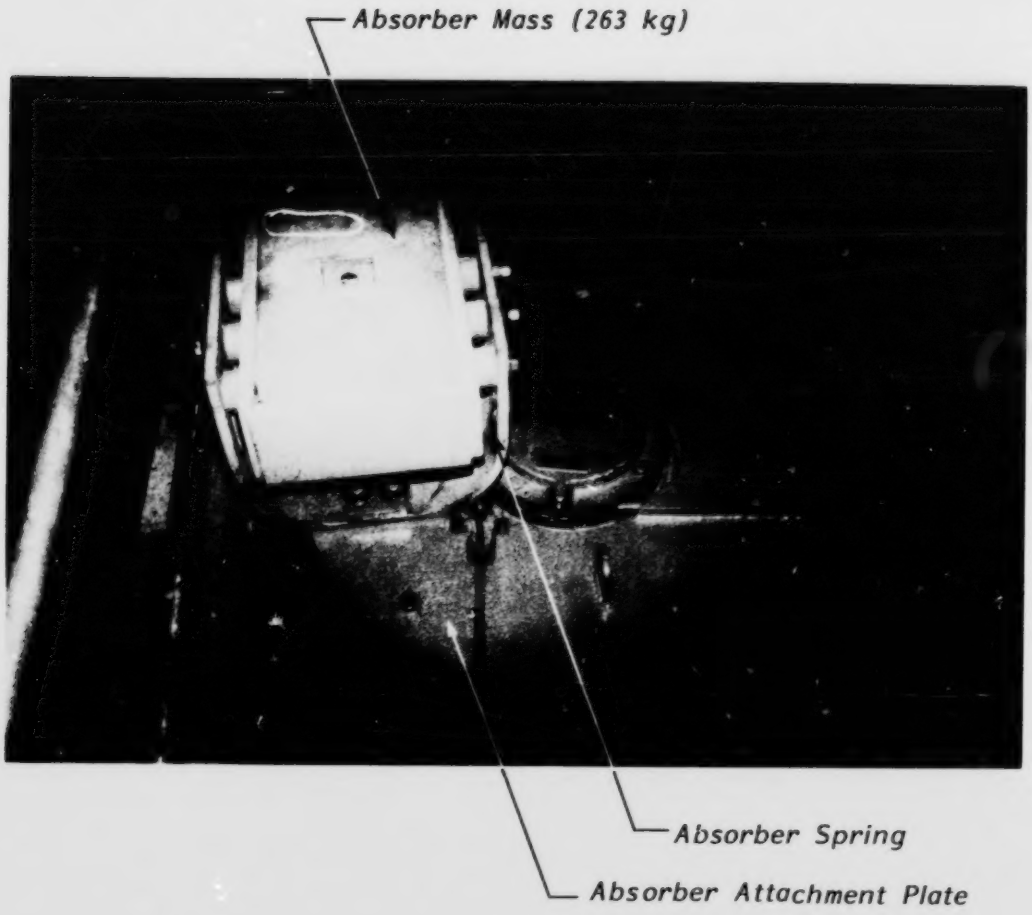


FIGURE 4
THE UNDAMPED DYNAMIC VIBRATION ABSORBER

176033-RD

BRUCE GSA ECI REC P#21 MOTOR TOP E-W NO ABS 00:41
200Hz A: AC/ 1V B: AC/ 5V S. SUM 8/8 DUAL 1k

		XFER FUNC MAG - PH	
1	15.750Hz	.215E-6 EU/EU	160.1 deg
2	19.000	.703E-6	77.9
3	19.750	.214E-6	25.5
4			
5			
6			
7			
8			
9			
10			

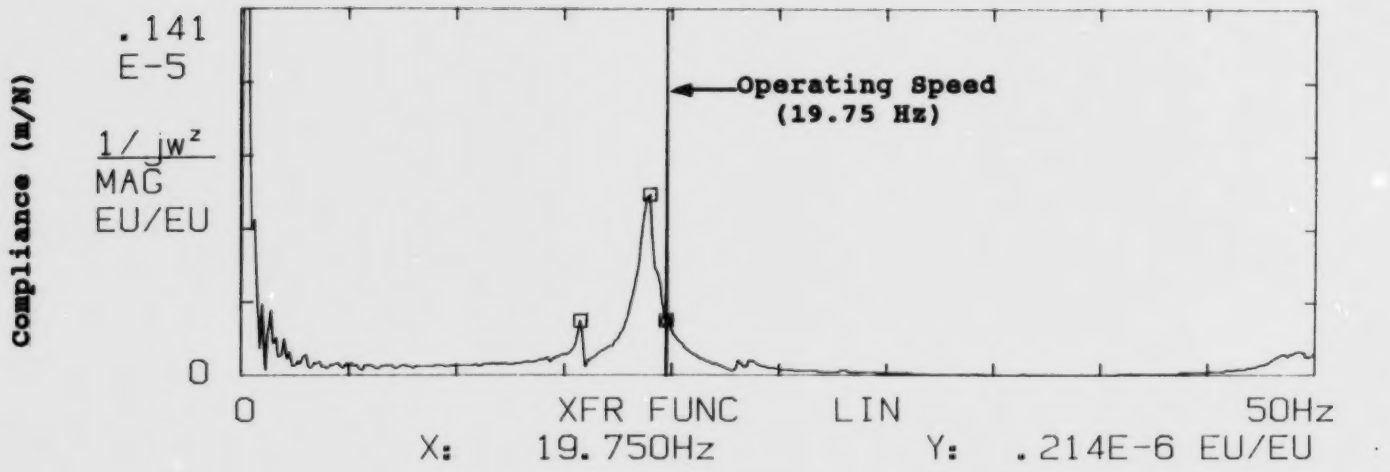


FIGURE 5
ECI RECOVERY PUMPSET #21 -TOP OF MOTOR CASING COMPLIANCE TRANSFER FUNCTION (E-W DIRECTION) WITHOUT ABSORBER

02:07

BRUCE GSA ECI REC P#21 MOTOR TOP N-S NO ABS IMP 00:52
200Hz A: AC/ 1V B: AC/ 5V S. SUM 8/8 DUAL 1k

		XFER FUNC MAG - PH	
1	16.250Hz	.544E-6 EU/EU	79.9 deg
2	19.750	.109E-7	-171.9
3	23.000	.115E-6	144.4
4	23.625	.916E-7	81.9
5	29.500	.893E-6	49.1
6	39.500	.130E-7	8.0
7			
8			
9			
10			

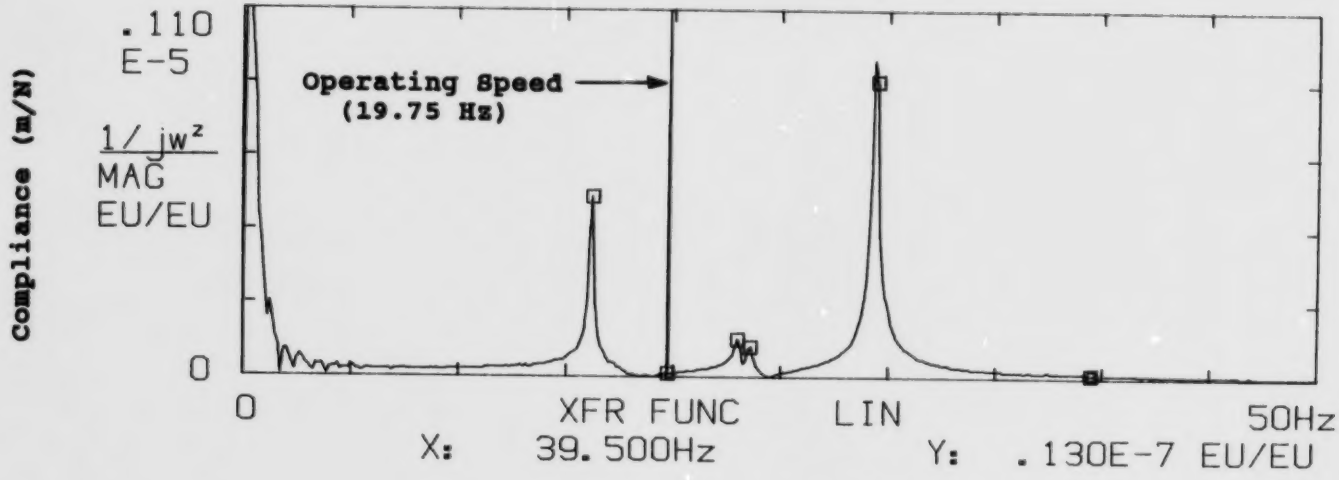


FIGURE 6
ECI RECOVERY PUMPSET #21 -TOP OF MOTOR CASING COMPLIANCE TRANSFER FUNCTION (N-S DIRECTION) WITHOUT ABSORBER

02:21

BRUCE GSA ECI REC P#21 MOTOR TOP E-W ABSORBER ON 02:17
100kHz A: AC/ 50V B: AC/ 50V INST 0/16 DUAL 1k

		XFER FUNC MAG - PH	
1	15.500Hz	.926E-6 EU/EU	62.3 deg
2	16.625	.930E-6	97.6
3	19.750	.216E-8	-27.4
4	22.250	.389E-6	81.4
5	23.750	.232E-6	65.6
6			
7			
8			
9			
10			

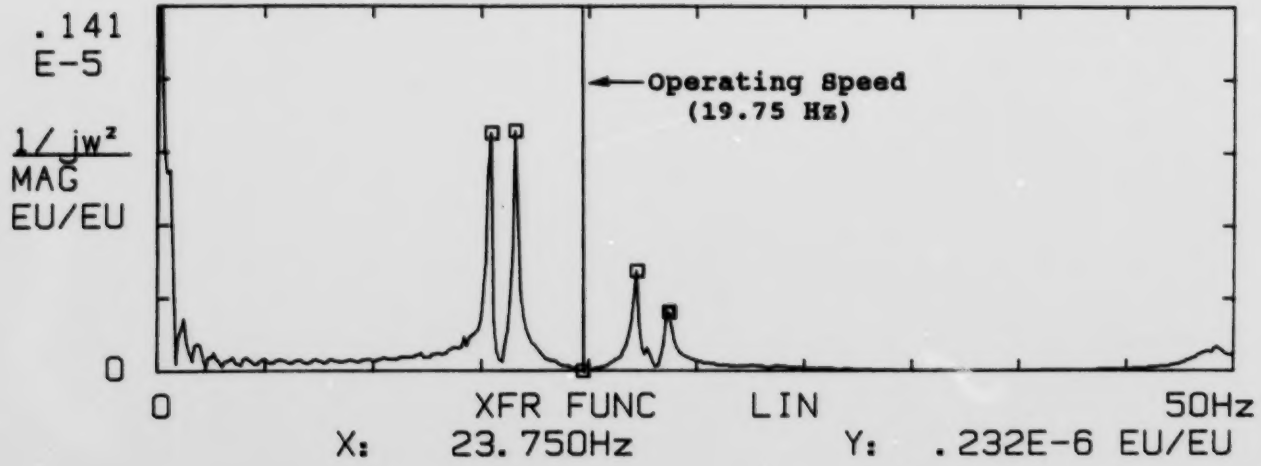


FIGURE 7
ECI RECOVERY PUMPSET #21 -TOP OF MOTOR CASING COMPLIANCE TRANSFER FUNCTION (E-W DIRECTION) WITH ABSORBER

00:07

87-301

BRUCE GSA ECI REC P#22 MOTOR TOP E-W NO ABS IMP 01:03
200Hz A: AC/ 1V B: AC/ 5V S. SUM 8/8 DUAL 1k

		XFER FUNC MAG - PH	
1	16.250Hz	.127E-6 EU/EU	166.4 deg
2	19.625	.122E-5	50.9
3	19.750	.593E-6	18.7
4			
5			
6			
7			
8			
9			
10			

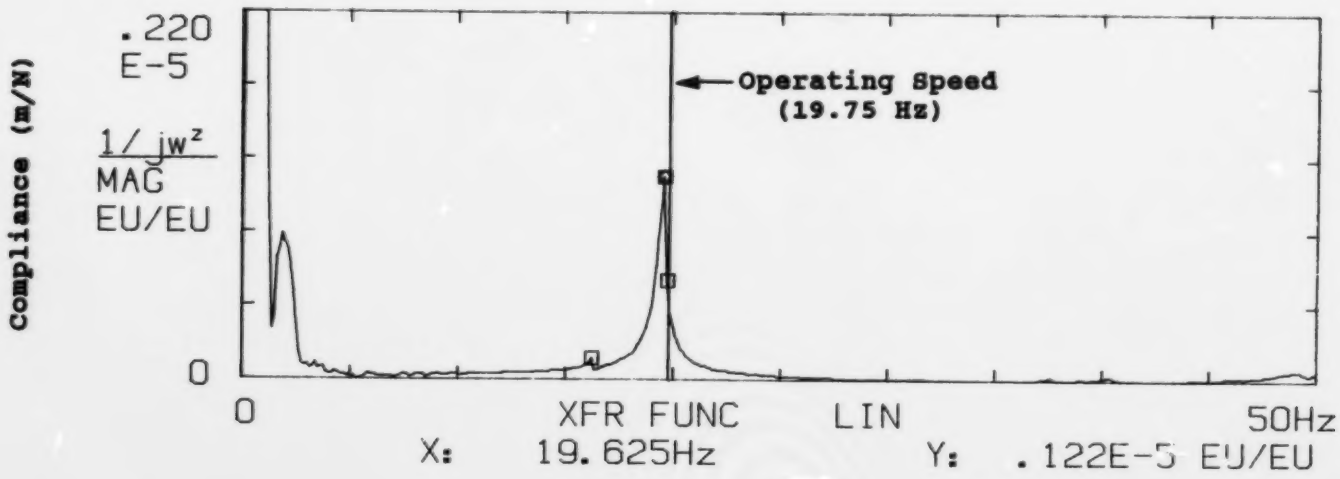


FIGURE 9
ECI RECOVERY PUMPSET #22 -TOP OF MOTOR CASING COMPLIANCE TRANSFER FUNCTION (E-W DIRECTION) WITHOUT ABSORBER

02:37

BRUCE GSA ECI REC P#21 MOTOR TOP N-S ABSORBER ON 02:23
100kHz A: AC/ 50V B: AC/ 50V INST 0/16 DUAL 1k

		XFER FUNC MAG - PH	
1	15.875Hz	.683E-6 EU/EU	108.1 deg
2	19.750	.112E-7	177.4
3	22.750	.265E-6	86.7
4	26.625	.355E-6	76.5
5	39.625	.863E-7	78.6
6			
7			
8			
9			
10			

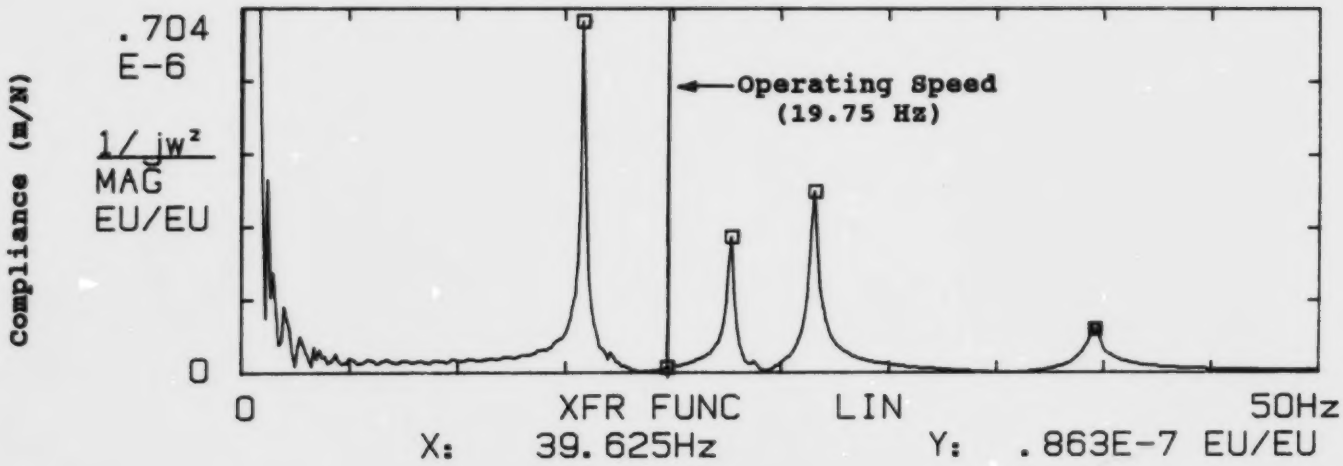


FIGURE 8
ECI RECOVERY PUMPSET #21 -TOP OF MOTOR CASING COMPLIANCE TRANSFER FUNCTION (N-S DIRECTION) WITH ABSORBER

00:10

87-301

BRUCE GSA ECI REC P#22 MOTOR TOP N-S NO ABS IMP 01:11
200Hz A: AC/ 1V B: AC/ 5V S. SUM 8/8 DUAL 1k

		XFER FUNC MAG - PH	
1	17.000Hz	.380E-6 EU/EU	83.6 deg
2	19.750	.143E-8	129.4
3	28.625	.105E-5	99.6
4	39.500	.152E-7	15.2
5			
6			
7			
8			
9			
10			

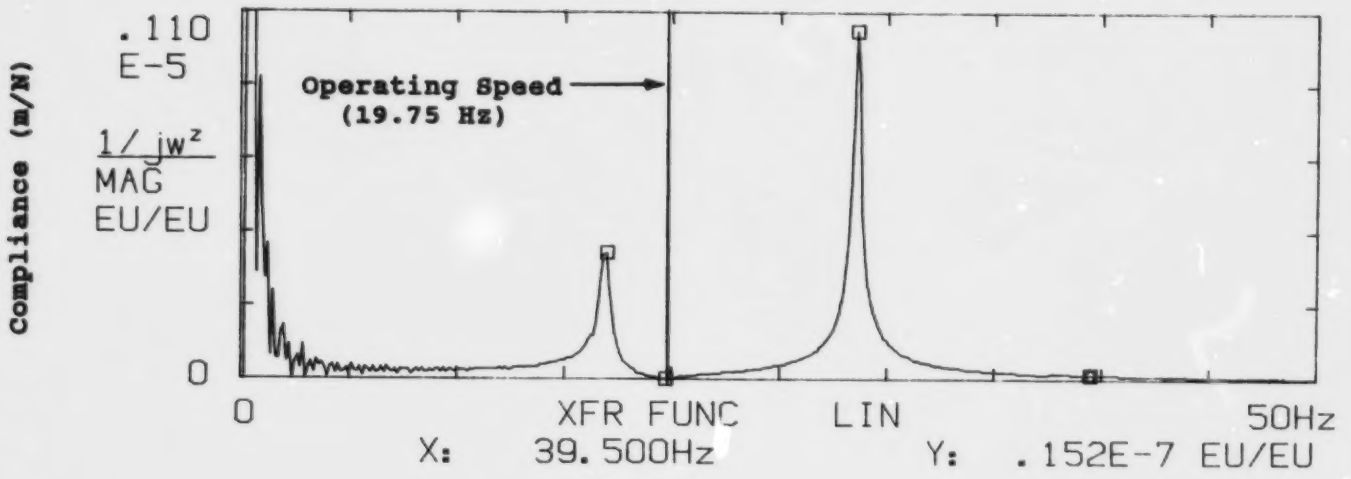


FIGURE 10
ECI RECOVERY PUMPSET #22 -TOP OF MOTOR CASING COMPLIANCE TRANSFER FUNCTION (N-S DIRECTION) WITHOUT ABSORBER

02:46

87-301

BRUCE GSA ECI REC P#22 MOTOR TOP E-W ABSORBER ON 00:52
100kHz A: AC/ 50V B: AC/ 50V INST 0/16 DUAL 1k

		XFER FUNC MAG - PH	
1	16.000Hz	.112E-5 EU/EU	104.3 deg
2	17.000	.499E-6	91.1
3	19.750	.366E-8	39.6
4	22.750	.328E-6	102.6
5			
6			
7			
8			
9			
10			

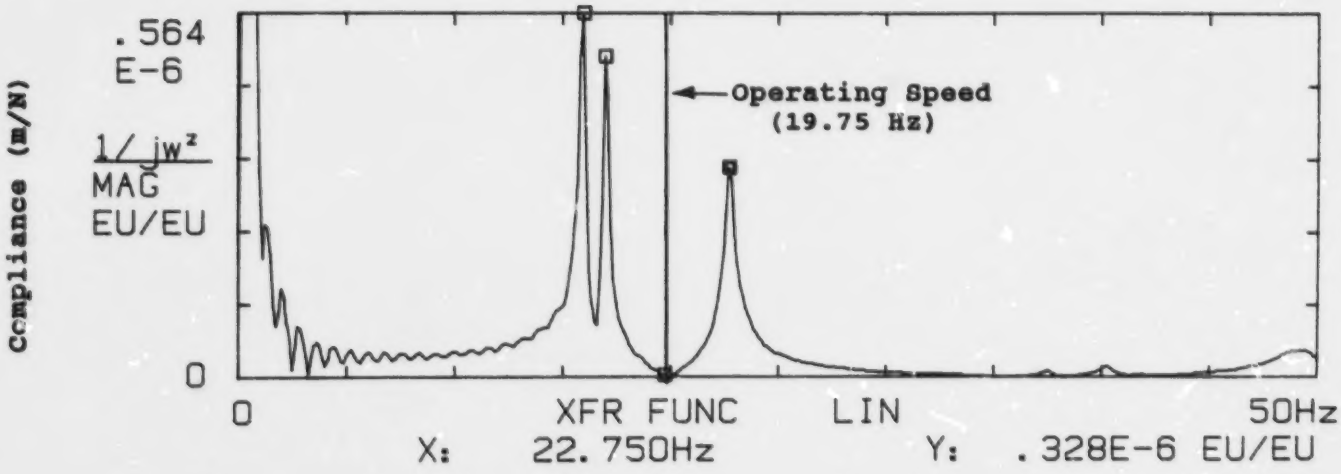


FIGURE 11
ECI RECOVERY PUMPSET #22 -TOP OF MOTOR CASING COMPLIANCE TRANSFER FUNCTION (E-W DIRECTION) WITH ABSORBER

00:13

BRUCE GSA ECI REC P#22 MOTOR TOP N-S ABSORBER ON 01:03
100kHz A: AC/ 50V B: AC/ 50V INST 0/16 DUAL 1k

		XFER FUNC MAG - PH	
1	16.375Hz	.596E-6 EU/EU	118.7 deg
2	19.750	.135E-8	145.9
3	25.750	.756E-6	93.9
4			
5			
6			
7			
8			
9			
10			

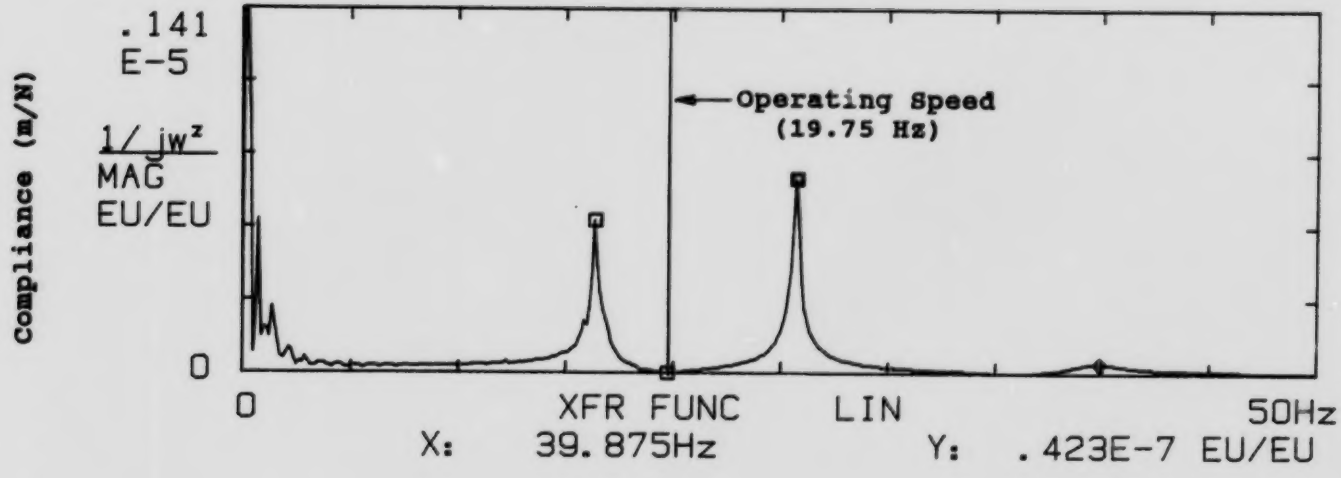


FIGURE 12
ECI RECOVERY PUMPSET #22 -TOP OF MOTOR CASING COMPLIANCE TRANSFER FUNCTION (N-S DIRECTION) WITH ABSORBER

00:16

87-301

IMPACT BRUCE NGSA ECIS PUMP#23 TOP OF MOTOR E-W 01:39
100kHz A: AC/ 50V B: AC/ 50V INST 16/16 DUAL 1k

		XFER FUNC MAG - PH	
1	15.625Hz	.217E-6 EU/EU	99.4 deg
2	19.750	.210E-5	23.3
3	22.750	.231E-6	93.7
4			
5			
6			
7			
8			
9			
10			

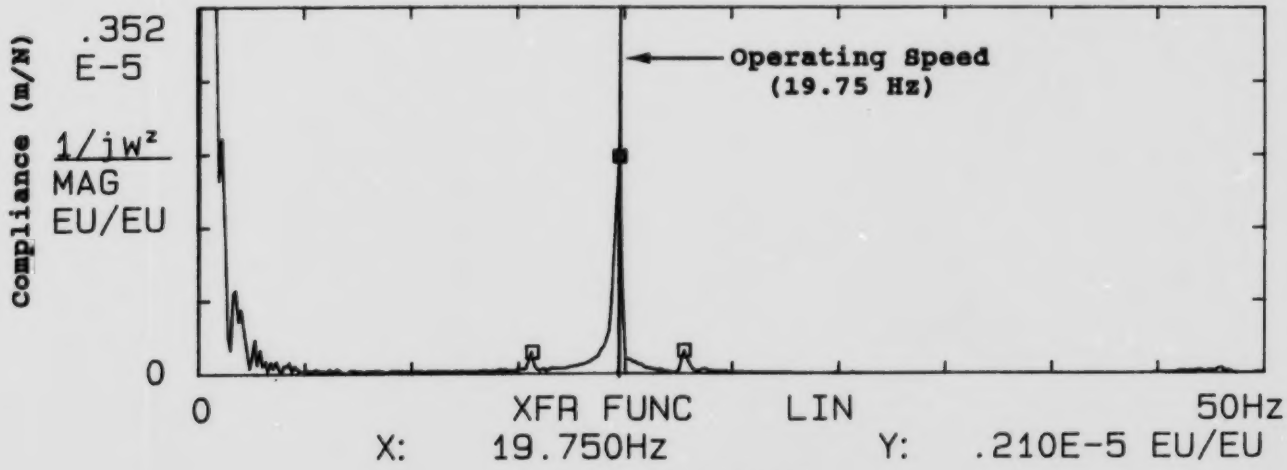


FIGURE 13
ECI RECOVERY PUMPSET #23 -TOP OF MOTOR CASING COMPLIANCE TRANSFER FUNCTION (E-W DIRECTION) WITHOUT ABSORBER

02:34

87-301

BRUCE GSA ECI REC P#23 MOTOR TOP E-W ABS IMP 01:21
200Hz A: AC/ 1V B: AC/ 5V S. SUM 8/8 DUAL 1k

		XFER FUNC MAG - PH	
1	15.500Hz	.112E-5 EU/EU	125.8 deg
2	16.625	.799E-6	78.1
3	19.750	.227E-8	134.4
4	22.000	.322E-6	117.4
5	22.875	.164E-6	62.7
6	23.500	.382E-6	100.8
7	39.500	.268E-8	159.1
8	46.375	.730E-7	95.9
9			
10			

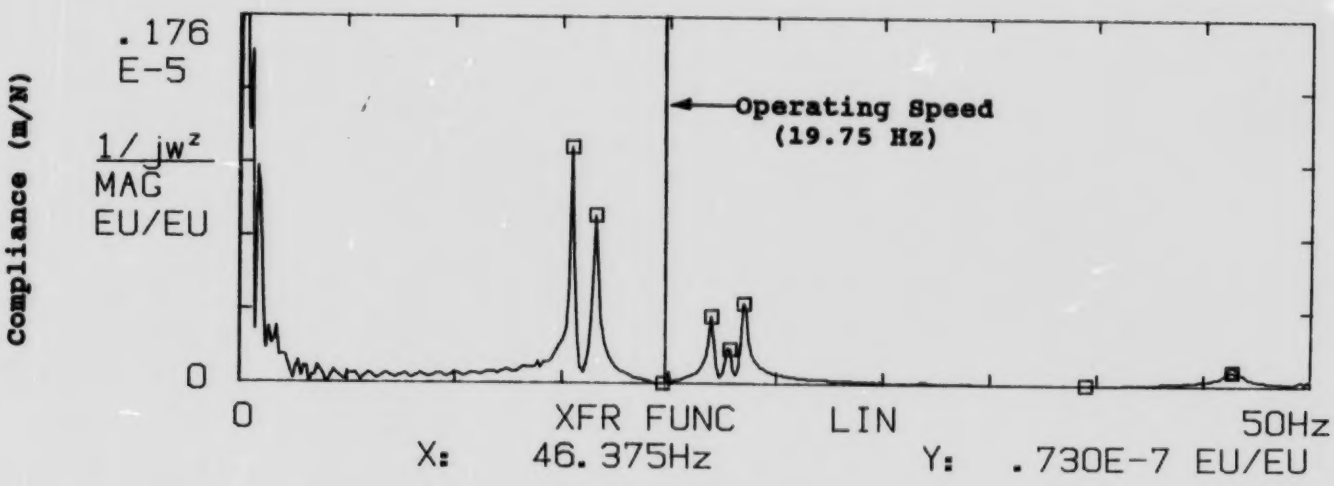


FIGURE 14
ECI RECOVERY PUMPSET #23 -TOP OF MOTOR CASING COMPLIANCE TRANSFER FUNCTION (E-W DIRECTION) WITH ABSORBER

02:52

87-301

BRUCE GSA ECI REC P#23 MOTOR TOP N-S ABS IMP 01:26
200Hz A: AC/ 1V B: AC/ 5V S. SUM 8/8 DUAL 1k

		XFER FUNC MAG - PH	
1	16.000Hz	.736E-6 EU/EU	79.3 deg
2	19.750	.142E-7	180.0
3	22.750	.332E-6	112.3
4	23.625	.713E-7	42.1
5	25.375	.265E-7	135.6
6	27.000	.315E-6	82.6
7	39.750	.962E-7	60.7
8			
9			
10			

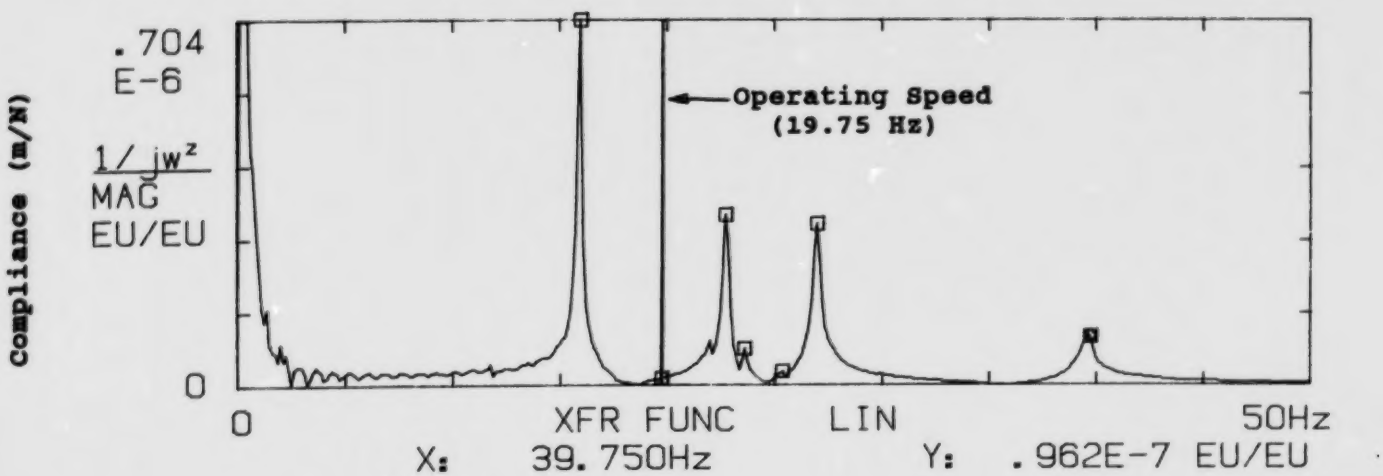


FIGURE 15
ECI RECOVERY PUMPSET #23 -TOP OF MOTOR CASING COMPLIANCE TRANSFER FUNCTION (N-S DIRECTION) WITH ABSORBER

03:01

87-301

BRUCE GSA ECI REC P#24 MOTOR TOP E-W NO ABS IMP 01:35
200Hz A: AC/ 1V B: AC/ 5V S. SUM 8/8 DUAL 1k

		XFER FUNC MAG - PH	
1	19.000Hz	.133E-5 EU/EU	82.9 deg
2	19.750	.223E-6	14.7
3			
4			
5			
6			
7			
8			
9			
10			

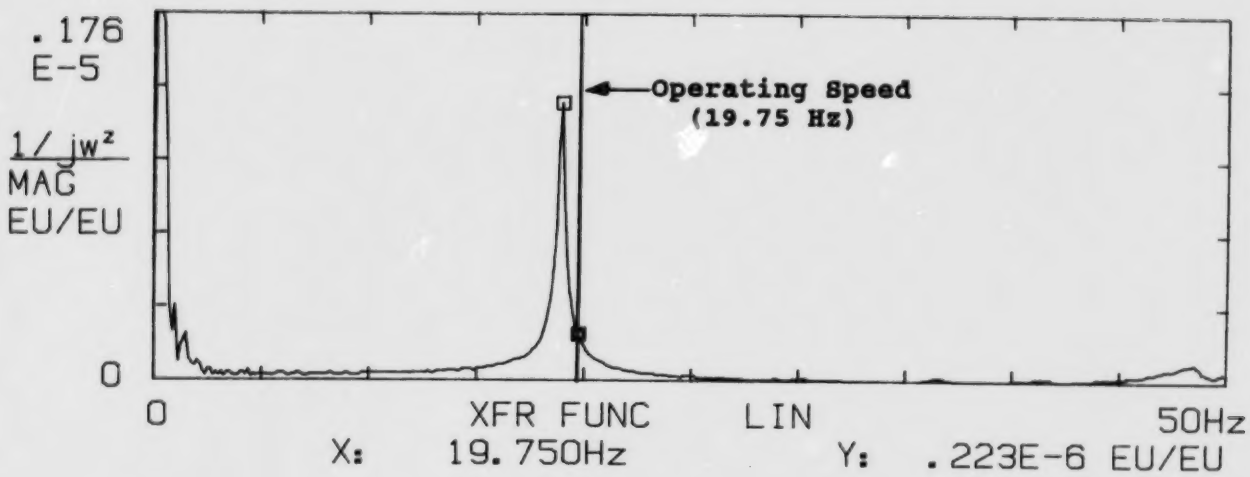


FIGURE 16
ECI RECOVERY PUMPSET #24 -TOP OF MOTOR CASING COMPLIANCE TRANSFER FUNCTION (E-W DIRECTION) WITHOUT ABSORBER

03:04

87-301

BRUCE GSA ECI REC P#24 MOTOR TOP N-S NO ABS IMP 01:38
100kHz A: AC/ 1mV B: AC/ 1mV T. SUM 16/16 DUAL 1k

		XFER FUNC MAG - PH	
1	16.750Hz	.737E-6 EU/EU	65.9 deg
2	19.750	.590E-8	122.6
3	28.750	.143E-5	91.2
4			
5			
6			
7			
8			
9			
10			

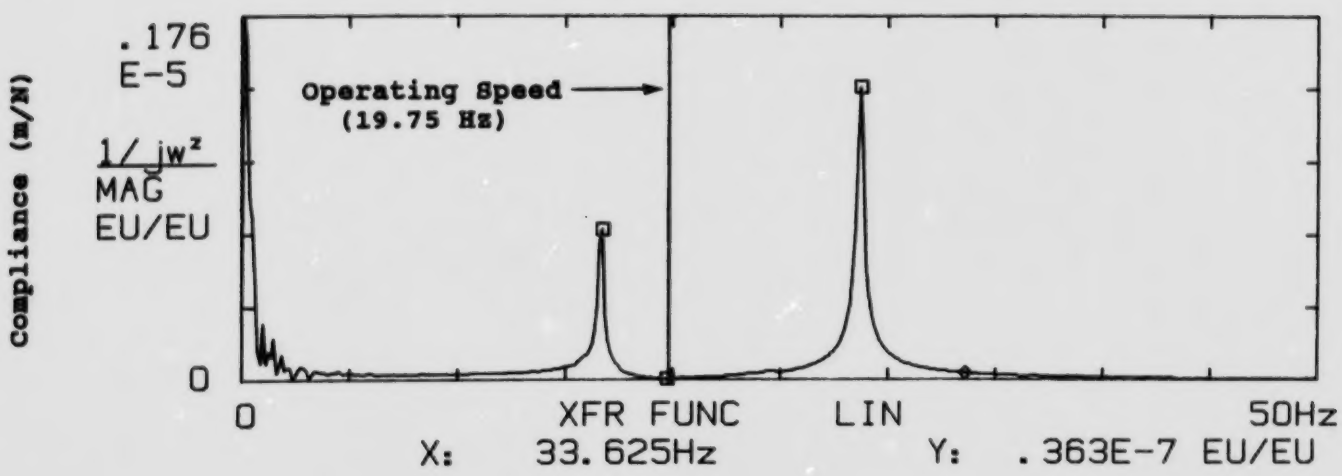


FIGURE 17
ECI RECOVERY PUMPSET #24 -TOP OF MOTOR CASING COMPLIANCE TRANSFER FUNCTION (N-S DIRECTION) WITHOUT ABSORBER

20:14

BRUCE GSA ECI REC P#24 MOTOR TOP E-W ABSORBER ON
50Hz A: AC/0.5V B: AC/ 2V S. SUM 0/8 DUAL 1k

		XFER FUNC MAG - PH	
1	16.250Hz	.106E-5 EU/EU	108.4 deg
2	19.750	.185E-8	-50.9
3	19.875	.990E-9	120.2
4	22.500	.801E-6	96.6
5	36.625	.222E-7	78.1
6	39.500	.421E-8	165.8
7	41.500	.173E-7	132.2
8			
9			
10			

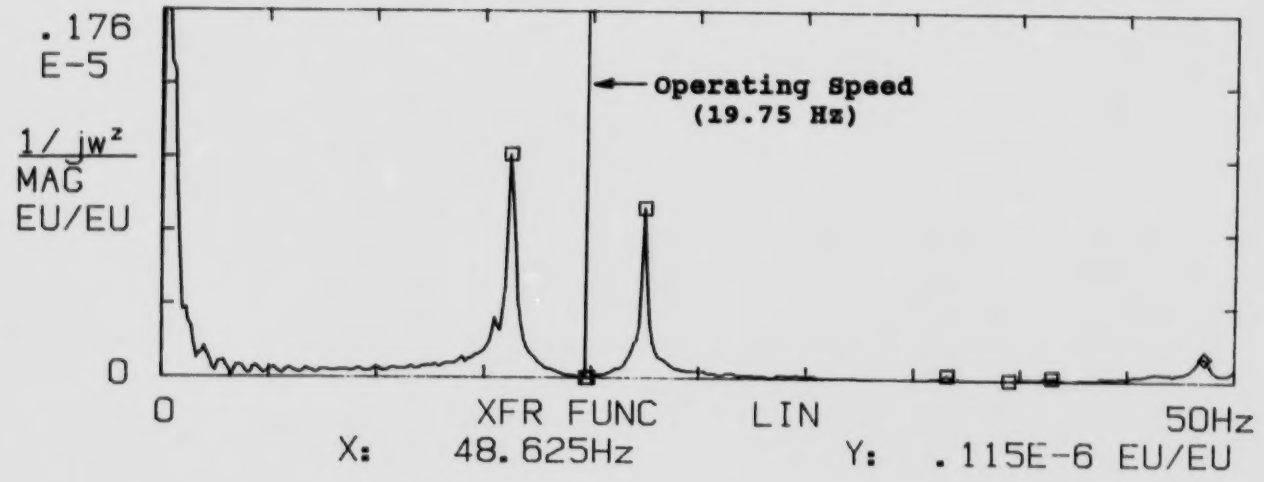


FIGURE 18
ECI RECOVERY PUMPSET #24 -TOP OF MOTOR CASING COMPLIANCE TRANSFER FUNCTION (E-W DIRECTION) WITH ABSORBER

01:57

87-301

BRUCE GSA ECI REC P#24 MOTOR TOP N-S ABSORBER ON
50Hz A: AC/0.5V B: AC/ 2V S.SUM 0/8 DUAL 1k

		XFER FUNC MAG - PH	
1	16.375Hz	.102E-5 EU/EU	107.5 deg
2	19.750	.289E-8	128.4
3	26.125	.792E-6	72.1
4	39.500	.225E-7	167.7
5	40.625	.119E-6	60.7
6			
7			
8			
9			
10			

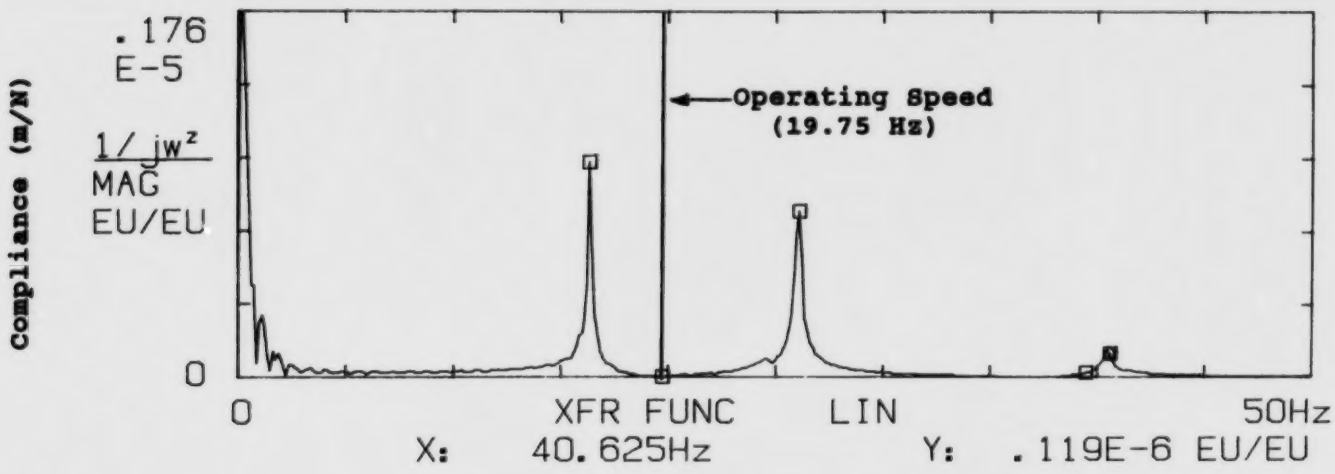
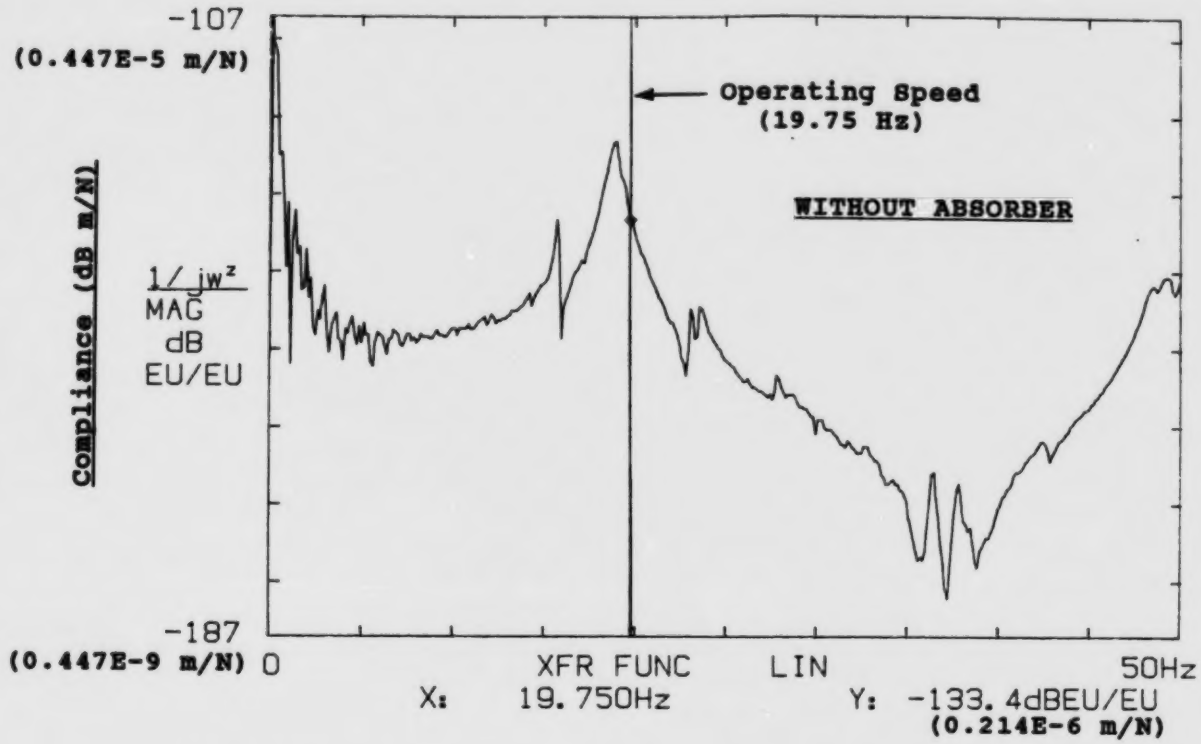


FIGURE 19
ECI RECOVERY PUMPSET #24 -TOP OF MOTOR CASING COMPLIANCE TRANSFER FUNCTION (N-S DIRECTION) WITH ABSORBER

01:48



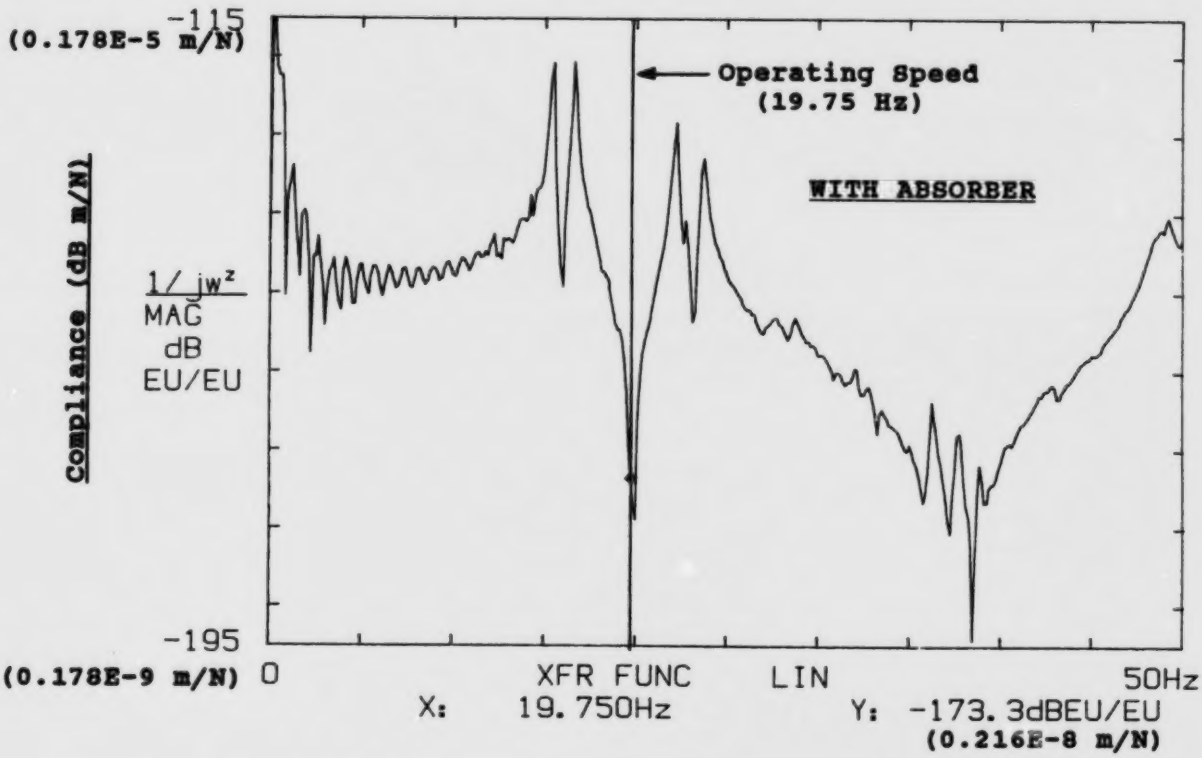
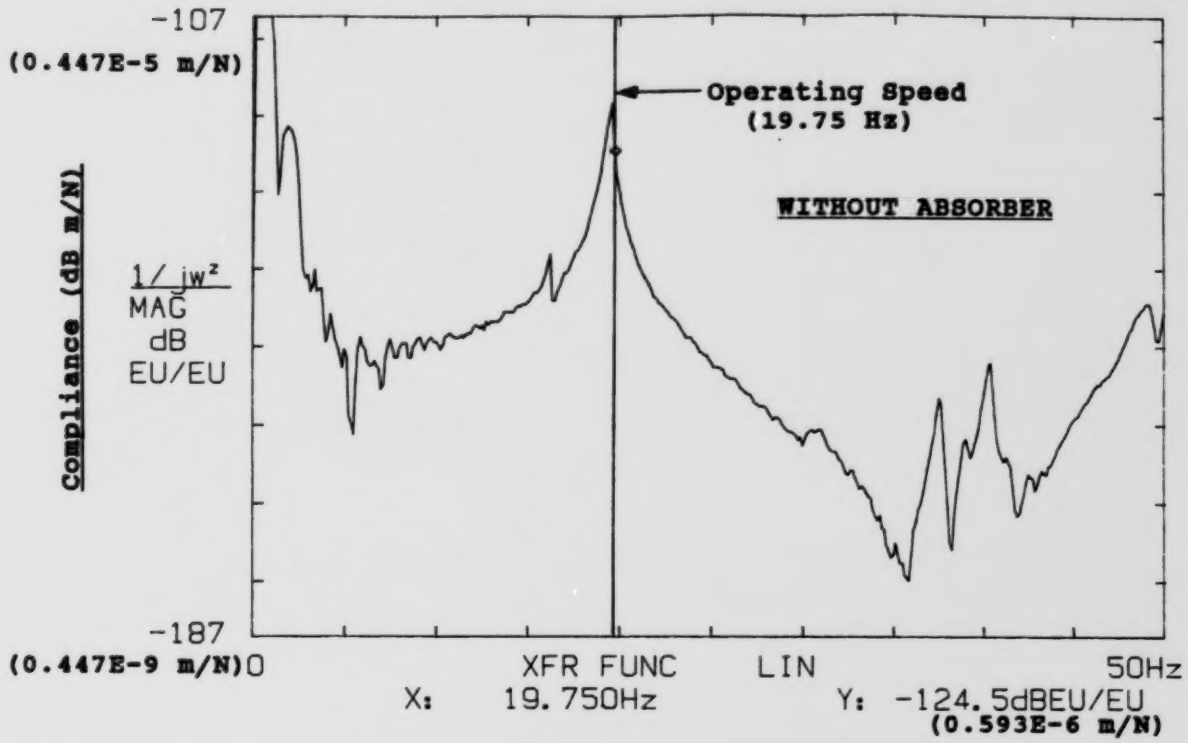


FIGURE 20
ECI RECOVERY PUMPSET #21 - TOP OF MOTOR CASING (E-W DIRECTION)
COMPLIANCE TRANSFER FUNCTION WITH AND WITHOUT VIBRATION ABSORBER



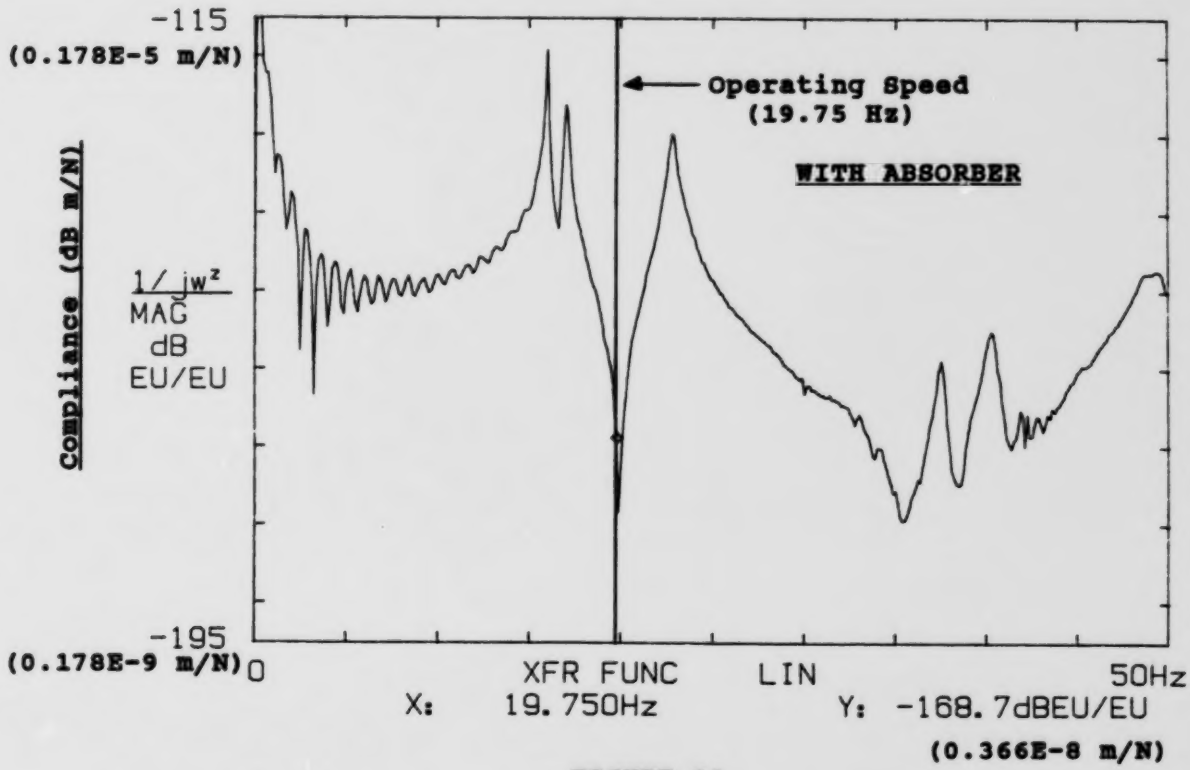


FIGURE 21
ECI RECOVERY PUMPSET #22 - TOP OF MOTOR CASING (E-W DIRECTION)
COMPLIANCE TRANSFER FUNCTION WITH AND WITHOUT VIBRATION ABSORBER

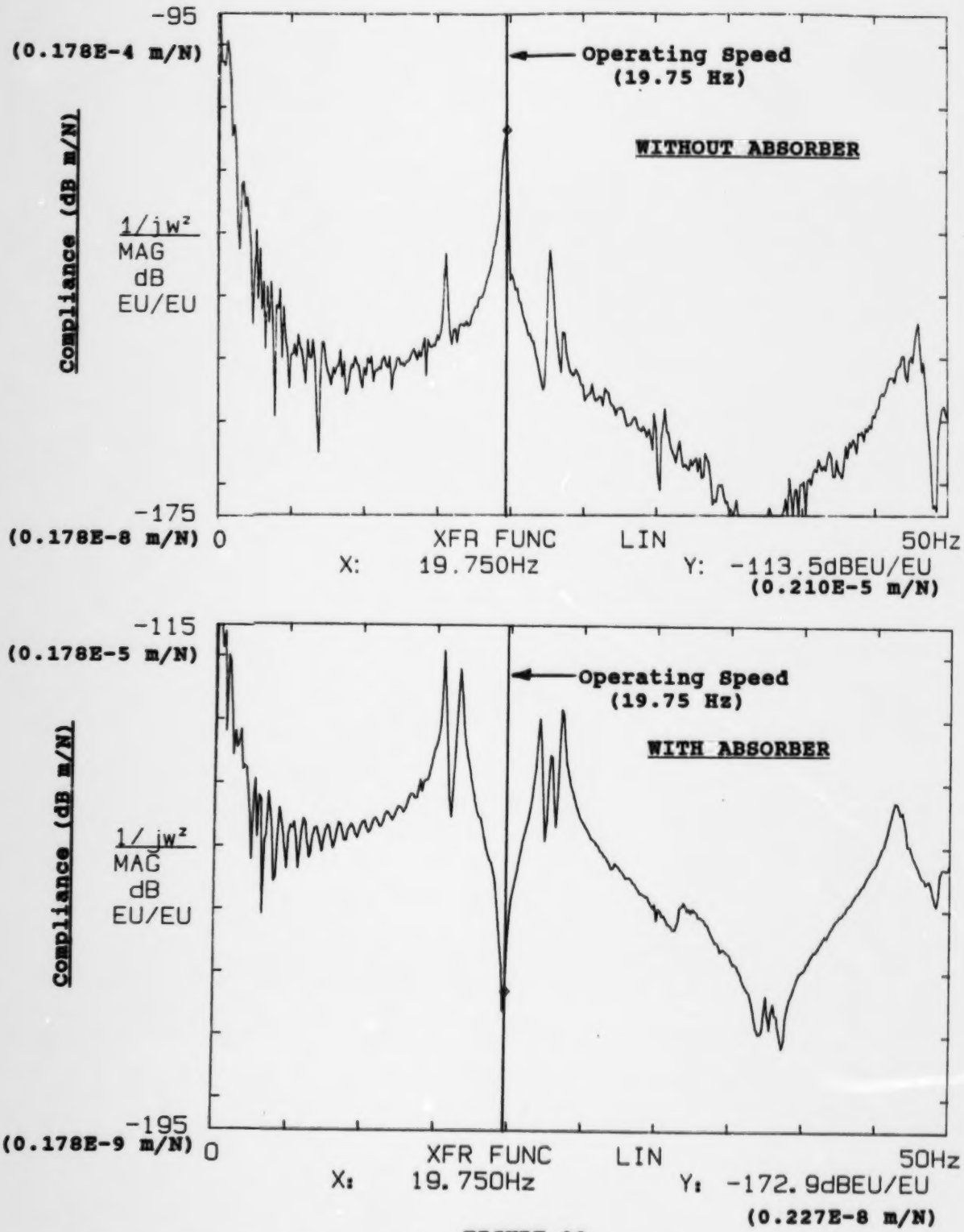
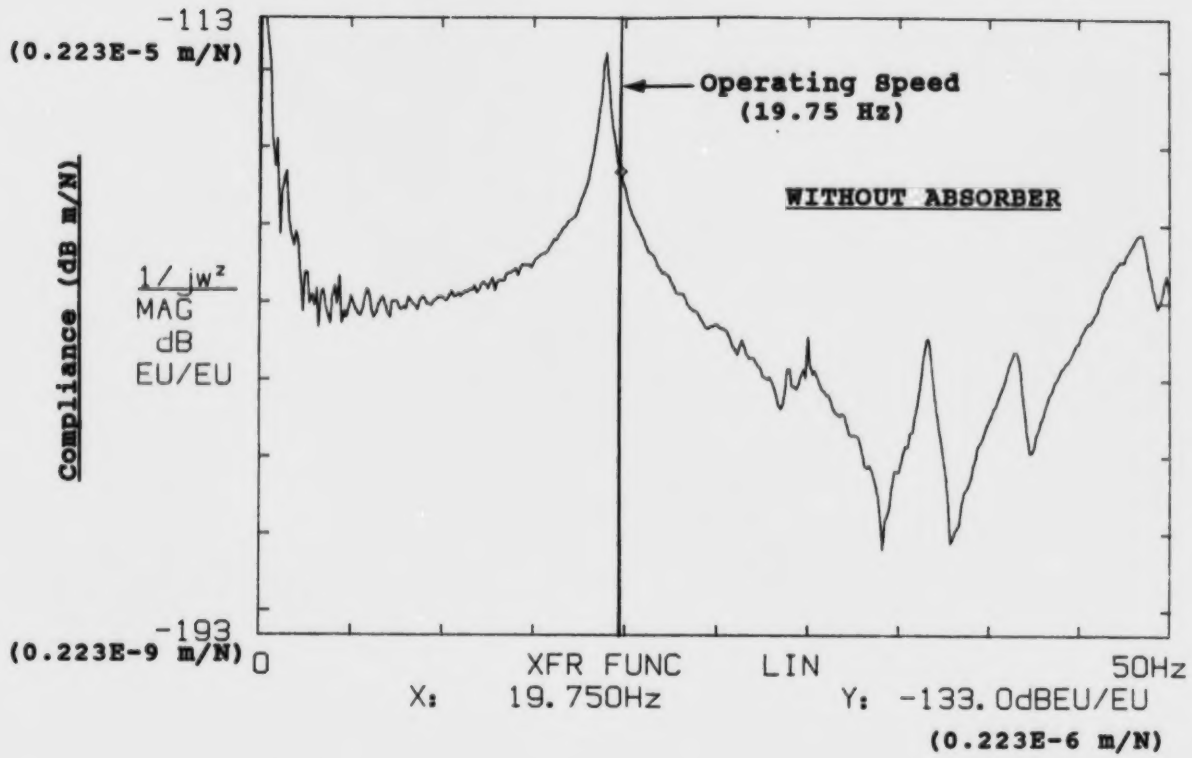


FIGURE 22
ECI RECOVERY PUMPSET #23 - TOP OF MOTOR CASING (E-W DIRECTION)
COMPLIANCE TRANSFER FUNCTION WITH AND WITHOUT VIBRATION ABSORBER



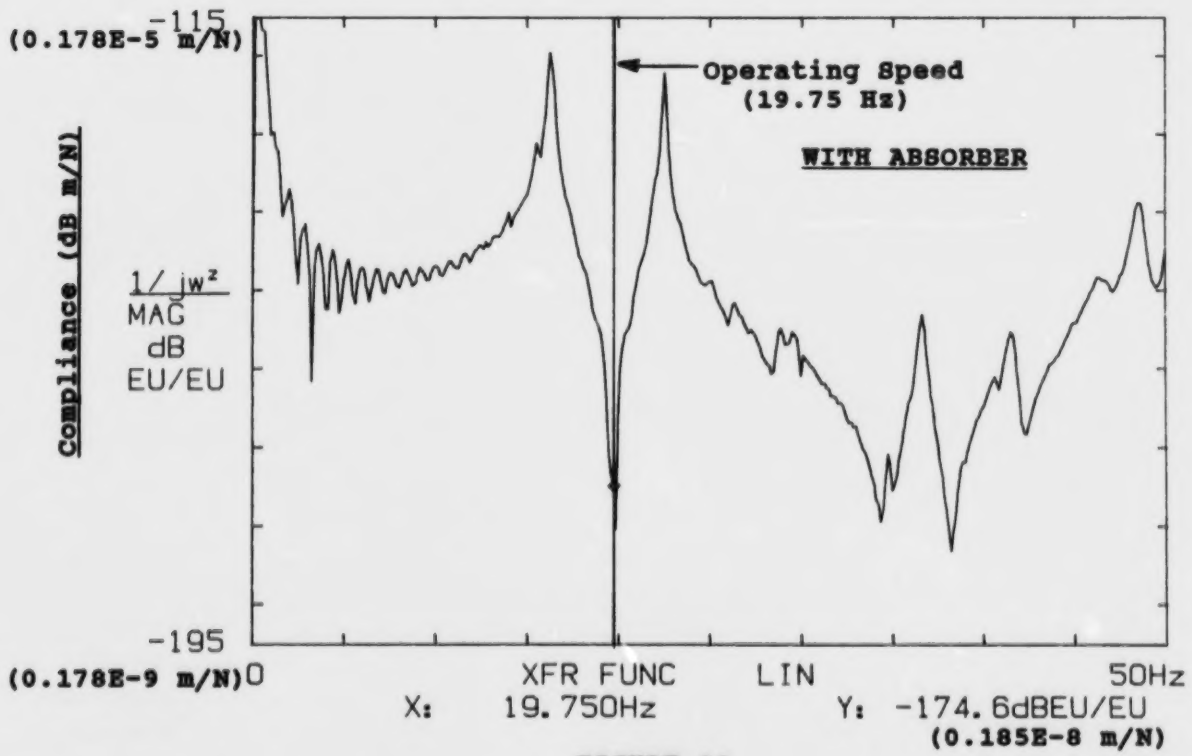


FIGURE 23
ECI RECOVERY PUMPSET #24 - TOP OF MOTOR CASING (E-W DIRECTION)
COMPLIANCE TRANSFER FUNCTION WITH AND WITHOUT VIBRATION ABSORBER

BRUCE GSA ECI REC P#21 MOTOR TOP E-W VEL NO ABS 00:58
100Hz A: AC/ 50V B: AC/ 50V S. SUM 8/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	18.75Hz	.101E+1	EU
2	19.75	.337E+1	
3	23.25	.556E+0	
4	79.00	.849E-1	
5			
6			
7			
8			
9			
10			

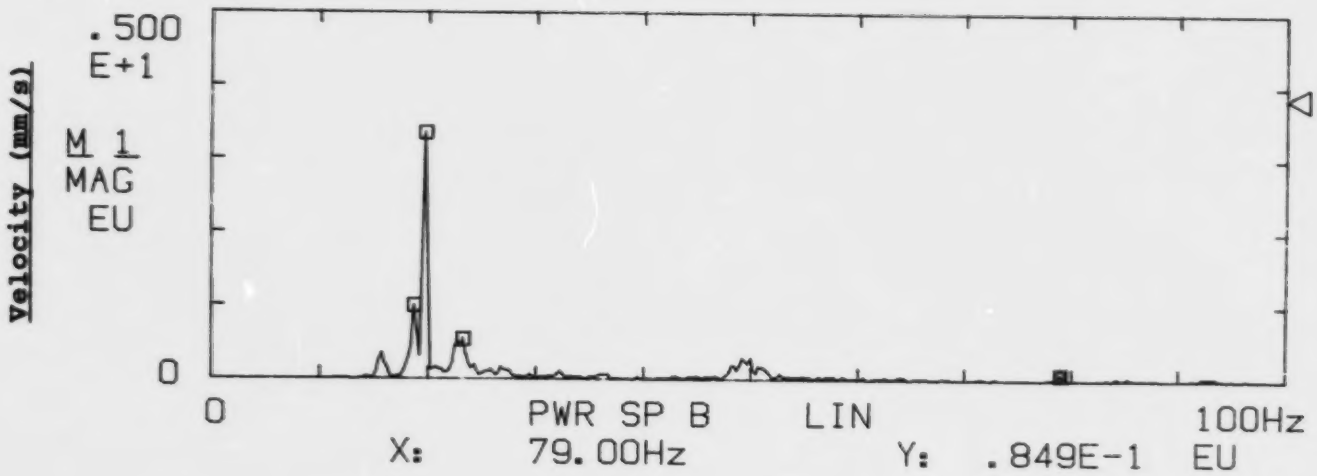


FIGURE 24
ECI RECOVERY PUMPSET #21 -TOP OF MOTOR CASING VELOCITY (E-W DIRECTION) WITHOUT ABSORBER

07:11

BRUCE GSA ECI REC P#21 MOTOR TOP N-S VEL NO ABS 01:05
100Hz A: AC/ 50V B: AC/ 50V S. SUM 8/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	16.25Hz	.702E+0	EU
2	19.75	.990E+0	
3	23.25	.103E+1	
4	24.00	.781E+0	
5	29.50	.146E+1	
6	39.50	.330E-1	
7	79.00	.791E-1	
8			
9			
10			

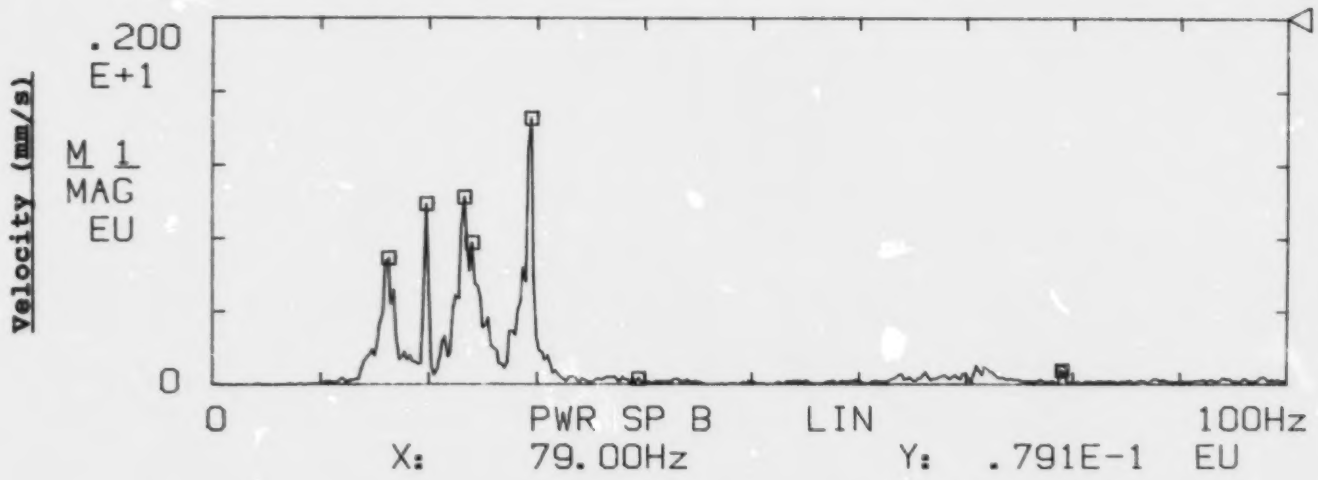


FIGURE 25
ECI RECOVERY PUMPSET #21 -TOP OF MOTOR CASING VELOCITY (N-S DIRECTION) WITHOUT ABSORBER

07:14

BRUCE GSA ECI REC P#21 MOTOR TOP AXI VEL NO ABS 01:09
100Hz A: AC/ 50V B: AC/ 50V S. SUM 8/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	16.25Hz	.582E-1	EU
2	19.75	.705E-1	
3	28.00	.624E-1	
4	29.00	.879E-1	
5	39.50	.865E-1	
6	42.25	.316E+0	
7	44.25	.430E+0	
8	46.00	.261E+0	
9	55.25	.276E+0	
10	79.00	.412E+0	

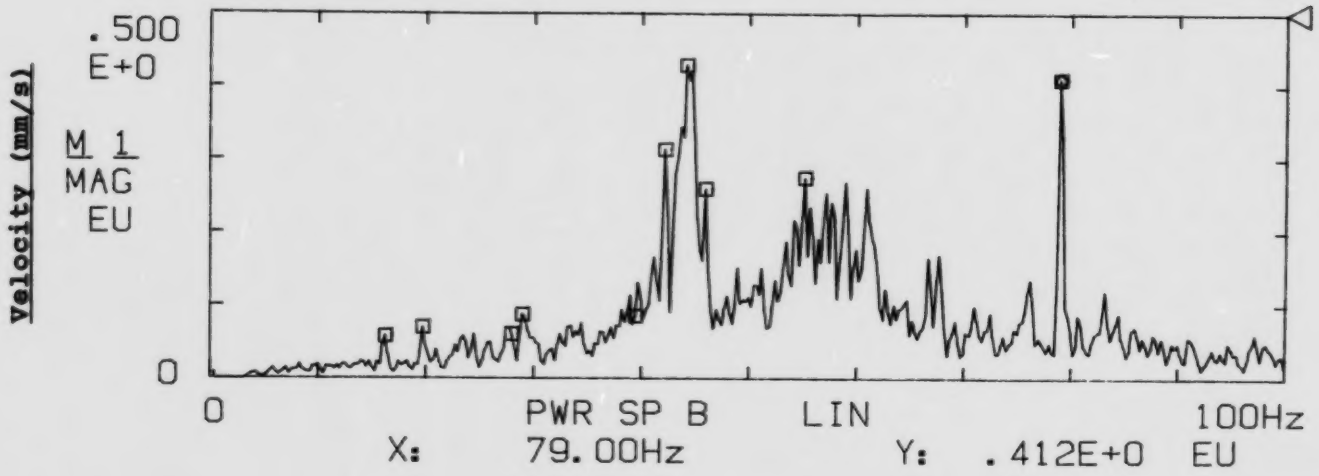


FIGURE 26
ECI RECOVERY PUMPSET #21 -TOP OF MOTOR CASING VELOCITY (AXIAL DIRECTION) WITHOUT ABSORBER

07:21

87-301

BRUCE GSA ECI REC P#21 MOTOR BOT E-W VEL NO ABS 01:12
100Hz A: AC/ 50V B: AC/ 50V S. SUM 8/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	19.75Hz	.199E+1	EU
2	22.75	.368E+0	
3	32.25	.749E-1	
4	39.50	.488E-2	
5	79.00	.450E-1	
6			
7			
8			
9			
10			

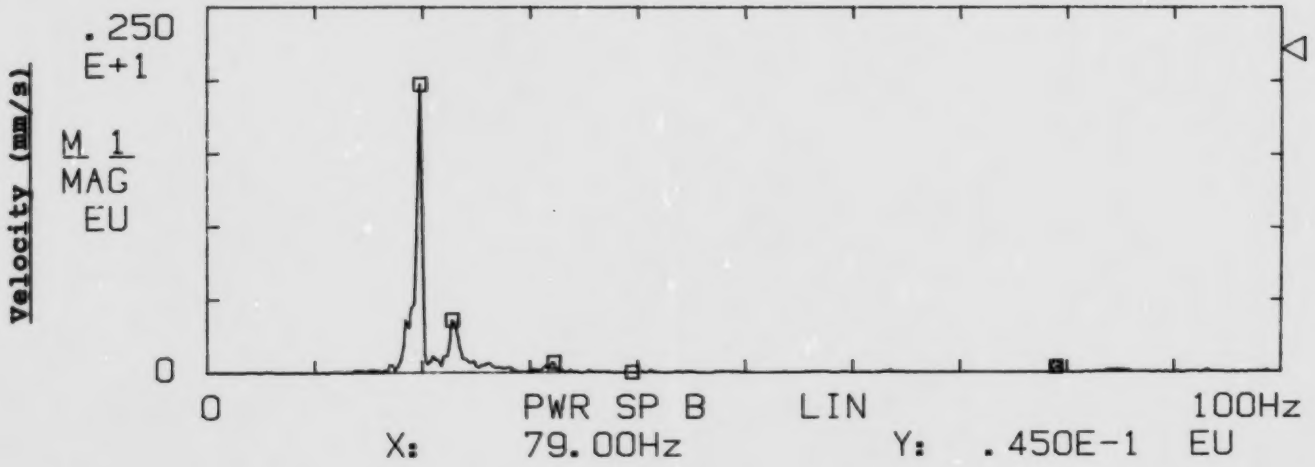


FIGURE 27
ECI RECOVERY PUMPSET #21 -BOTTOM OF MOTOR CASING VELOCITY (E-W DIRECTION) WITHOUT ABSORBER

07:23

87-301

BRUCE GSA ECI REC P#21 MOTOR BOT N-S VEL NO ABS 01:14
100Hz A: AC/ 50V B: AC/ 50V S. SUM 8/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	16.25Hz	.875E+0	EU
2	19.75	.661E+0	
3	22.75	.640E+0	
4	25.00	.239E+0	
5	26.50	.192E+0	
6	29.25	.551E+0	
7	30.50	.211E+0	
8			
9			
10			

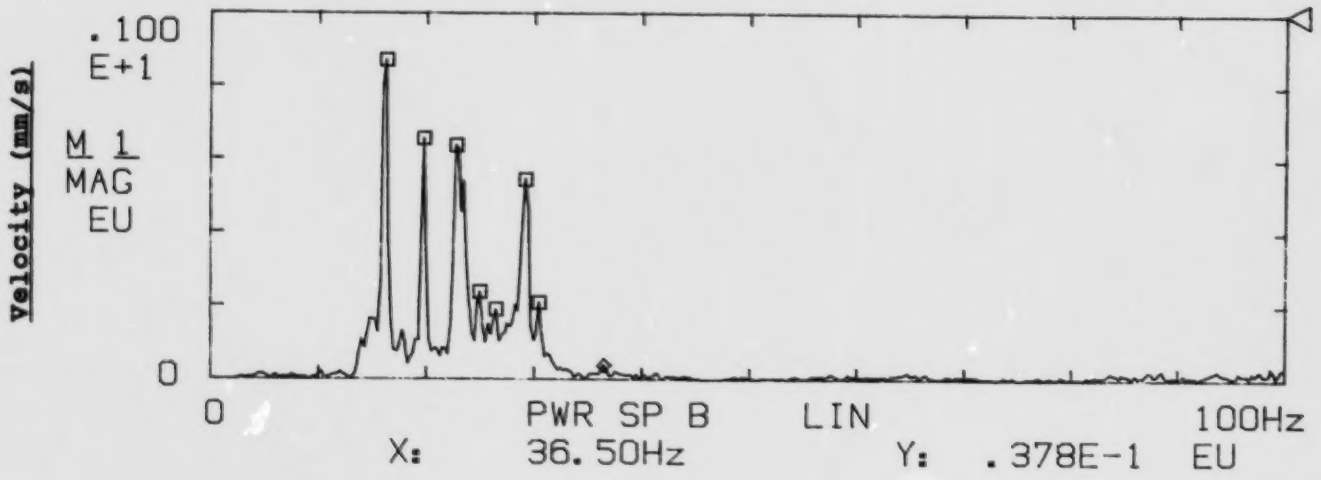


FIGURE 28
ECI RECOVERY PUMPSET #21 -BOTTOM OF MOTOR CASING VELOCITY (N-S DIRECTION) WITHOUT ABSORBER

07:26

87-301

BRUCE GSA ECI REC P#21 PUMP STOOL E-W NO ABS VEL 01:23
100Hz A: AC/ 50V B: AC/ 50V S. SUM 8/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	12.25Hz	.251E-1	EU
2	14.25	.682E-1	
3	15.50	.228E+0	
4	19.75	.159E+1	
5	23.50	.555E-1	
6	50.50	.958E-1	
7	79.00	.489E-1	
8			
9			
10			

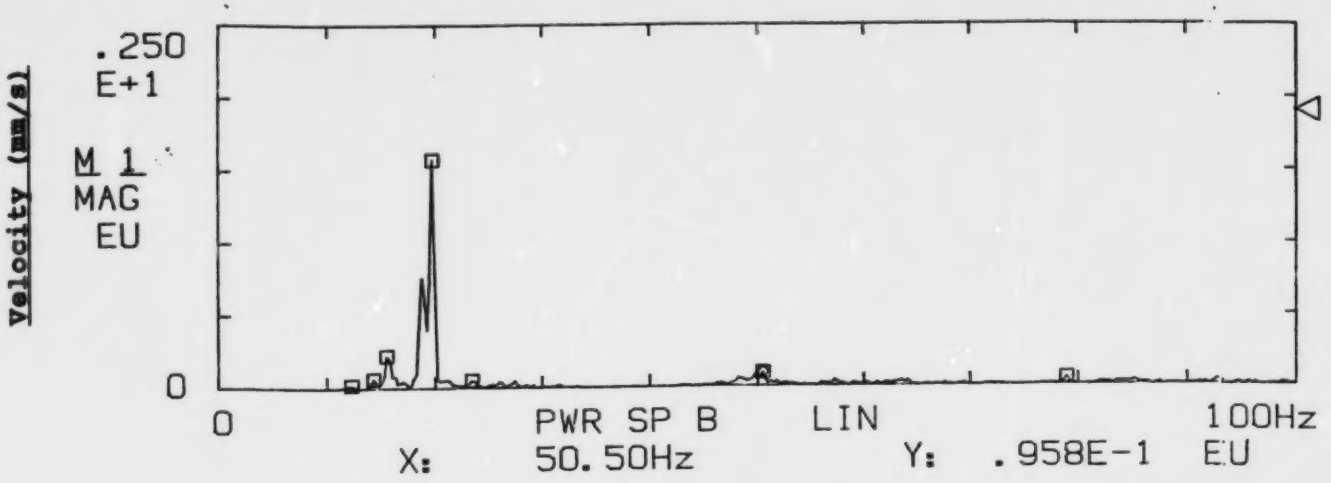


FIGURE 29
ECI RECOVERY PUMPSET #21 -PUMP STOOL VELOCITY (E-W DIRECTION) WITHOUT ABSORBER

BRUCE GSA ECI REC P#21 PUMP STOOL N-S NO ABS VEL 01:21
100Hz A: AC/ 50V B: AC/ 50V S. SUM 8/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	16.00Hz	.195E+0	EU
2	19.75	.149E+0	
3	23.00	.139E+0	
4	29.25	.146E+0	
5	79.00	.998E-1	
6			
7			
8			
9			
10			

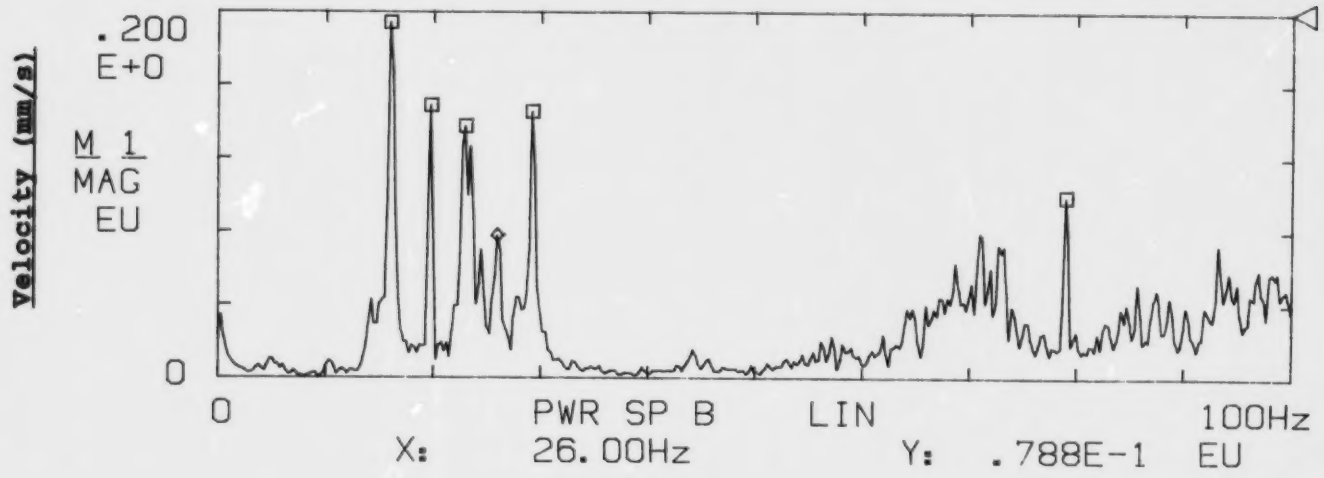


FIGURE 30
ECI RECOVERY PUMPSET #21 -PUMP STOOL VELOCITY (N-S DIRECTION) WITHOUT ABSORBER

07:57

87-301

BRUCE GSA ECI REC P#21 PUMP STOOL AXI NO ABS VEL 01:26
100Hz A: AC/ 50V B: AC/ 50V S. SUM 8/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	15.75Hz	.804E-1	EU
2	18.75	.105E+0	
3	19.75	.201E+0	
4	22.75	.930E-1	
5	43.75	.234E+0	
6	57.00	.174E+0	
7	64.75	.142E+0	
8	79.00	.218E+0	
9			
10			

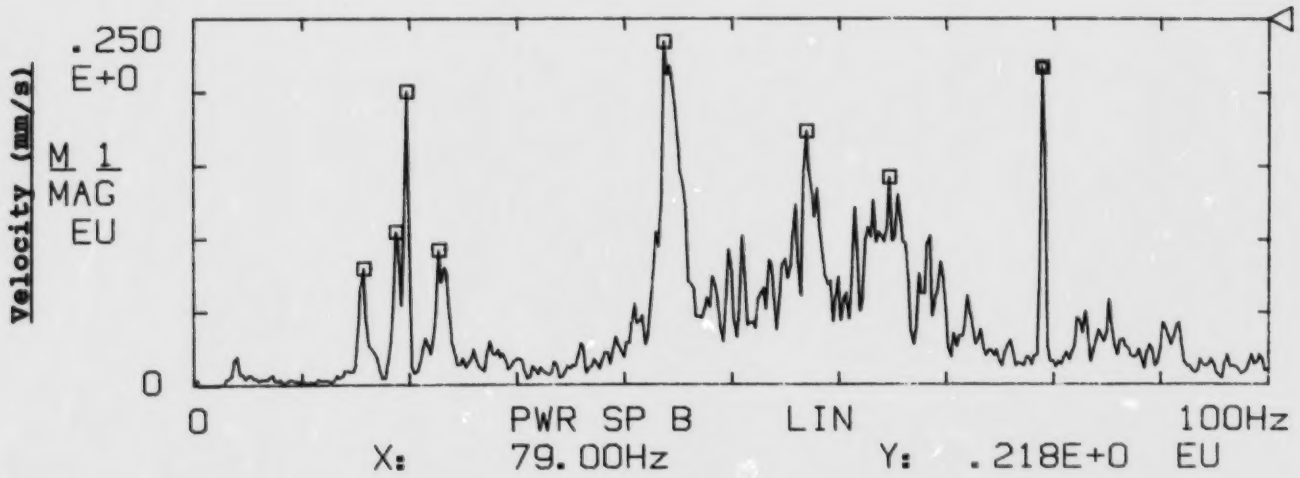


FIGURE 31
ECI RECOVERY PUMPSET #21 -PUMP STOOL VELOCITY (AXIAL DIRECTION) WITHOUT ABSORBER

07:33

87-301

BRUCE GSA ECI REC P#21 MOTOR TOP E-W VEL W/ABS 03:00
5kHz A: AC/ 50V B: AC/50mV S. SUM 32/32 DUAL 1k

	PWR SPECTRUM	ChB	
1	15.25Hz	.525E+0	EU
2	16.25	.452E+0	
3	19.75	.835E-1	
4	22.00	.866E+0	
5	22.50	.803E+0	
6	23.75	.829E+0	
7	27.50	.147E+0	
8	50.00	.212E+0	
9	79.00	.994E-1	
10			

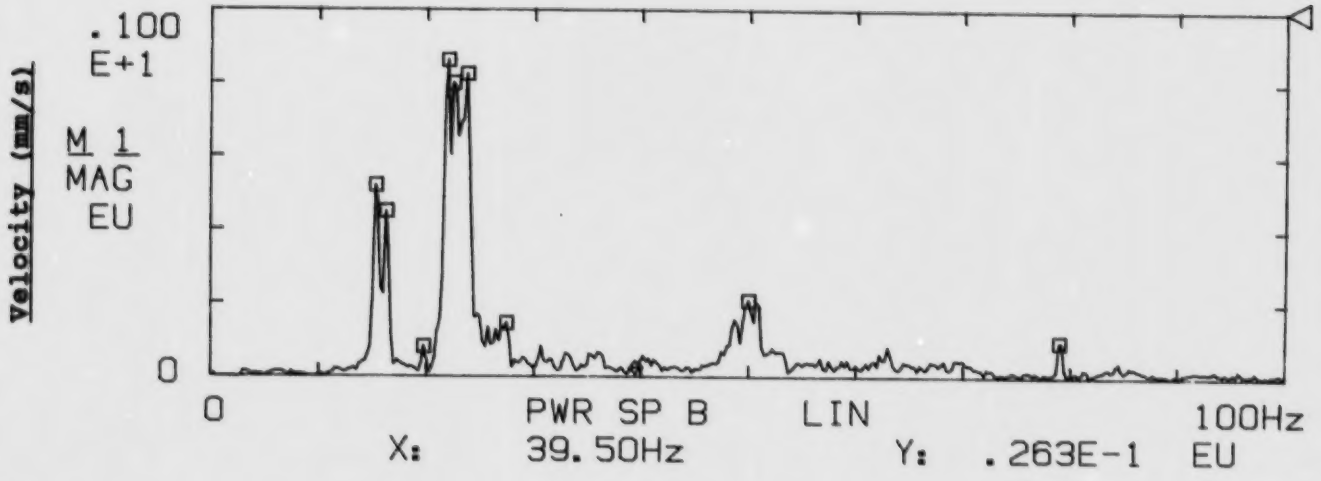


FIGURE 32
ECI RECOVERY PUMPSET #21 -TOP OF MOTOR CASING VELOCITY (E-W DIRECTION) WITH ABSORBER

04:50

BRUCE GSA ECI REC P#21 MOTOR TOP N-S VEL W/ABS 03:07
5kHz A: AC/ 50V B: AC/50mV S. SUM 32/32 DUAL 1k

	PWR SPECTRUM	ChB	
1	16.00Hz	.176E+1	EU
2	19.75	.107E+1	
3	22.50	.184E+1	
4	24.25	.609E+0	
5	26.25	.121E+1	
6	39.50	.411E+0	
7			
8			
9			
10			

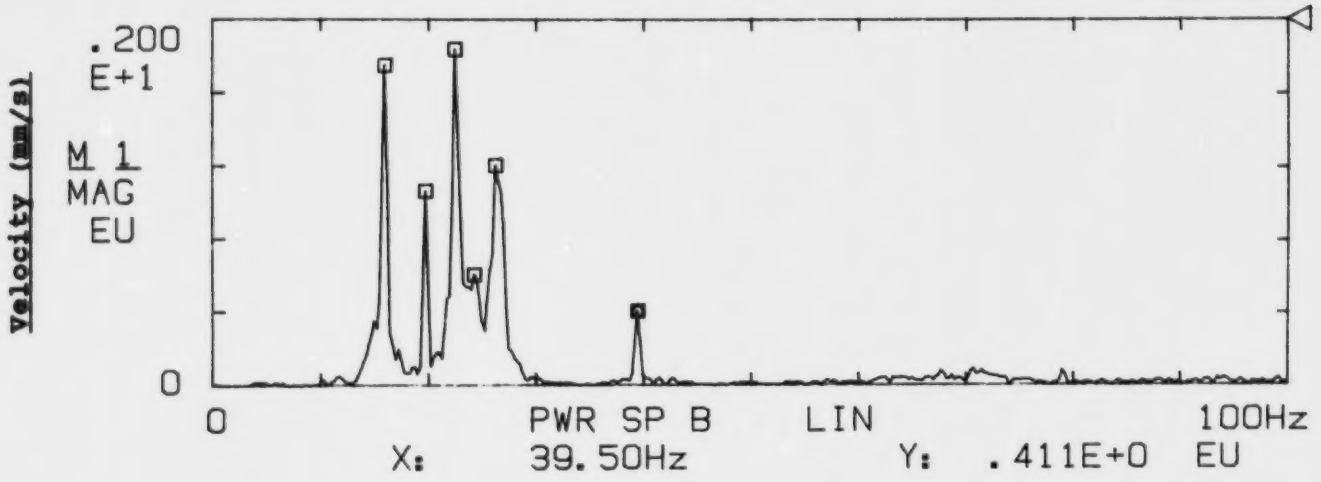


FIGURE 33
ECI RECOVERY PUMPSET #21 -TOP OF MOTOR CASING VELOCITY (N-S DIRECTION) WITH ABSORBER

05:02

87-301

BRUCE GSA ECI REC P#21 MOTOR TOP AXI VEL W/ABS 03:12
5kHz A: AC/ 50V B: AC/50mV S. SUM 32/32 DUAL 1k

	PWR SPECTRUM	ChB	
1	19.75Hz	.638E-1	EU
2	39.50	.519E-1	
3	42.75	.466E+0	
4	44.00	.453E+0	
5	55.50	.339E+0	
6	79.00	.330E+0	
7			
8			
9			
10			

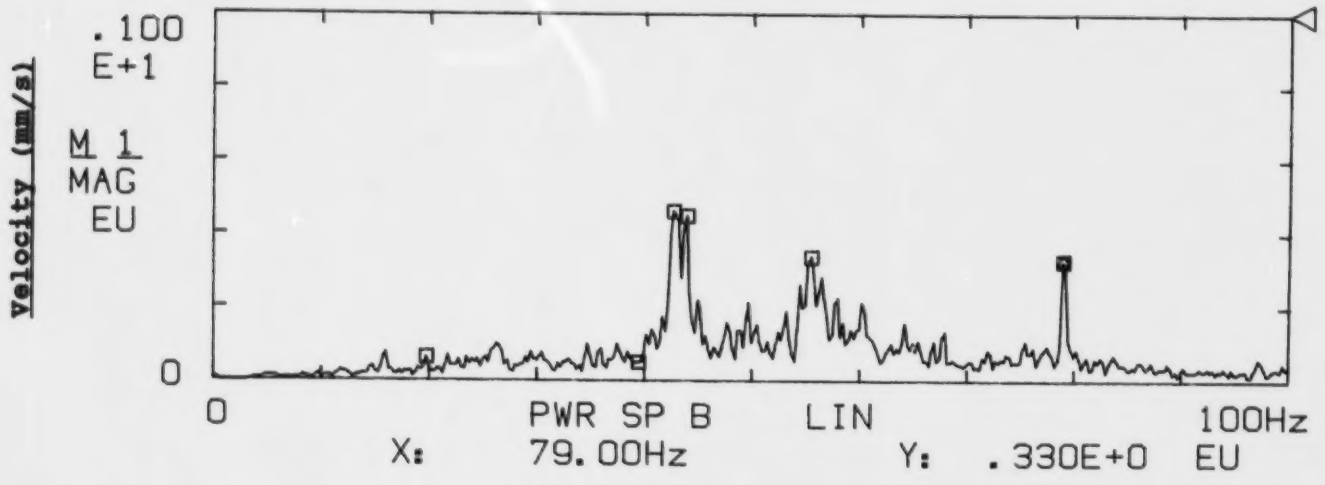


FIGURE 34
ECI RECOVERY PUMPSET #21 -TOP OF MOTOR CASING VELOCITY (AXIAL DIRECTION) WITH ABSORBER

05:09

87-301

BRUCE GSA ECI REC P#21 MOTOR BOT E-W VEL W/ABS 03:18
5kHz A: AC/ 50V B: AC/50mV S. SUM 32/32 DUAL 1k

	PWR SPECTRUM	ChB	
1	15.625Hz	.163E+0	EU
2	16.250	.222E+0	
3	19.750	.333E+0	
4	21.875	.507E+0	
5	22.250	.508E+0	
6	23.000	.452E+0	
7	23.750	.275E+0	
8			
9			
10			

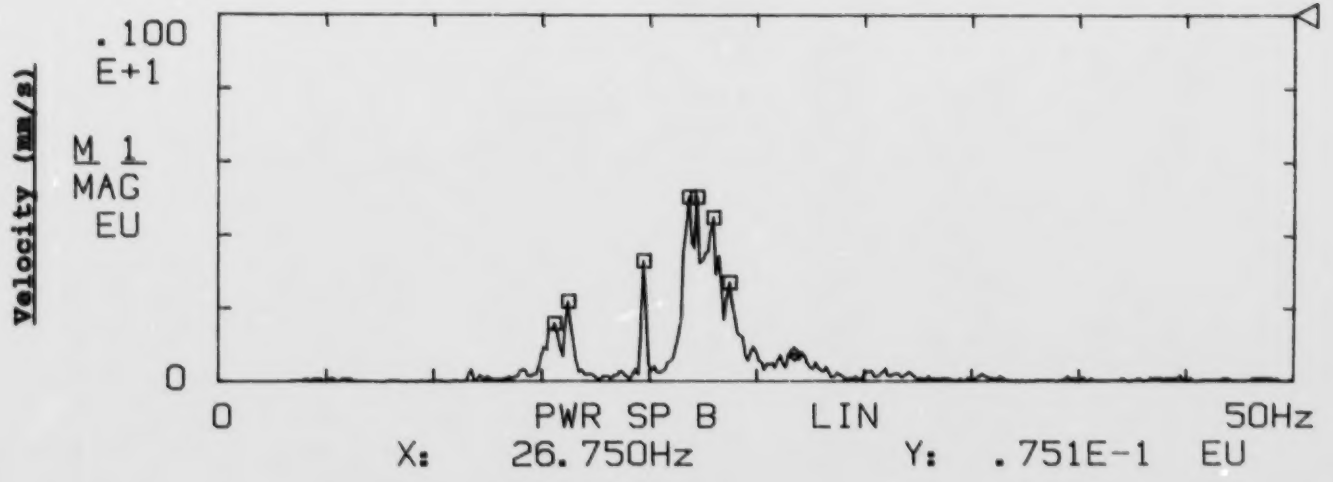


FIGURE 35
ECI RECOVERY PUMPSET #21 -BOTTOM OF MOTOR CASING VELOCITY (E-W DIRECTION) WITH ABSORBER

05:18

BRUCE GSA ECI REC P#21 MOTOR BOT N-S VEL W/ABS 03:20
5kHz A: AC/ 50V B: AC/50mV S. SUM 32/32 DUAL 1k

	PWR SPECTRUM	ChB	
1	15.75Hz	.687E+0	EU
2	19.75	.426E+0	
3	22.50	.562E+0	
4	24.50	.338E+0	
5	26.50	.940E+0	
6	39.50	.139E+0	
7			
8			
9			
10			

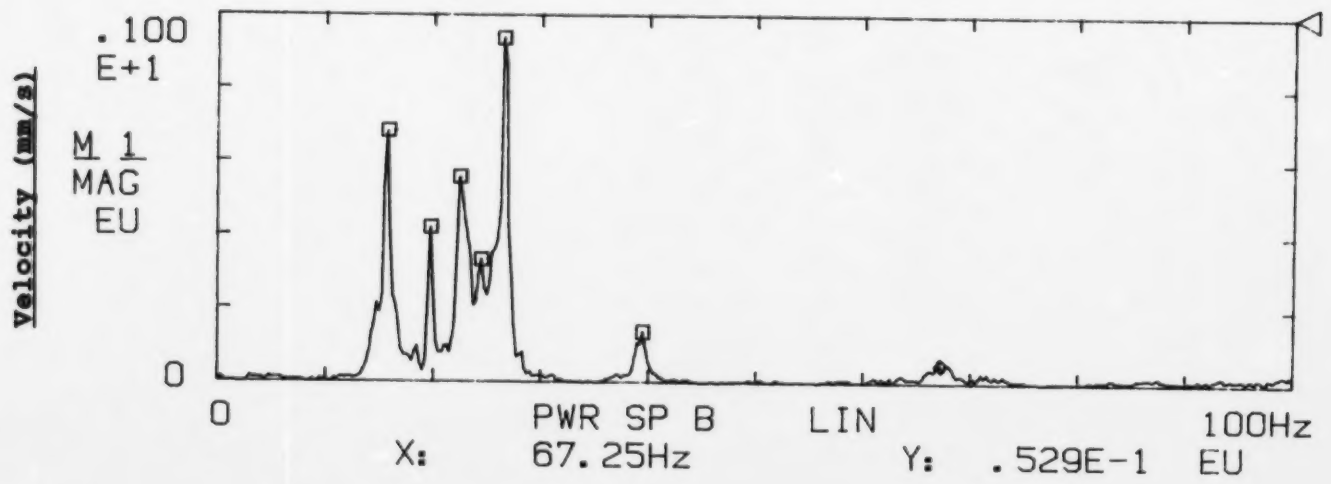


FIGURE 36
ECI RECOVERY PUMPSET #21 -BOTTOM OF MOTOR CASING VELOCITY (N-S DIRECTION) WITH ABSORBER

05:22

87-301

BRUCE GSA ECI REC P#21 PUMP STOOL E-W W/ABS VEL 03:28
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	16.50Hz	.188E+0	EU
2	19.75	.443E+0	
3	22.00	.628E+0	
4	23.25	.242E+0	
5	39.50	.117E-1	
6	49.00	.111E+0	
7	79.25	.603E-1	
8			
9			
10			

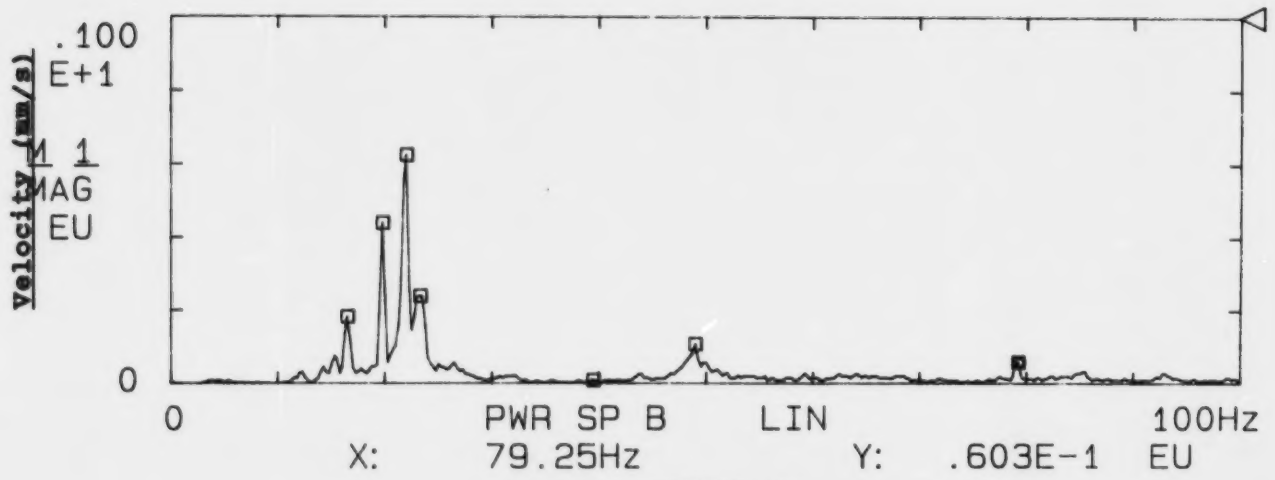


FIGURE 37
ECI RECOVERY PUMPSET #21 -PUMP STOOL VELOCITY (E-W DIRECTION) WITH ABSORBER

15:21

87-301

BRUCE GSA ECI REC P#21 PUMP STOOL N-S W/ABS VEL 03:26
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	15.75Hz	.142E+0	EU
2	19.75	.151E+0	
3	22.75	.186E+0	
4	25.50	.120E+0	
5	26.50	.295E+0	
6	39.50	.487E-1	
7	79.00	.100E+0	
8			
9			
10			

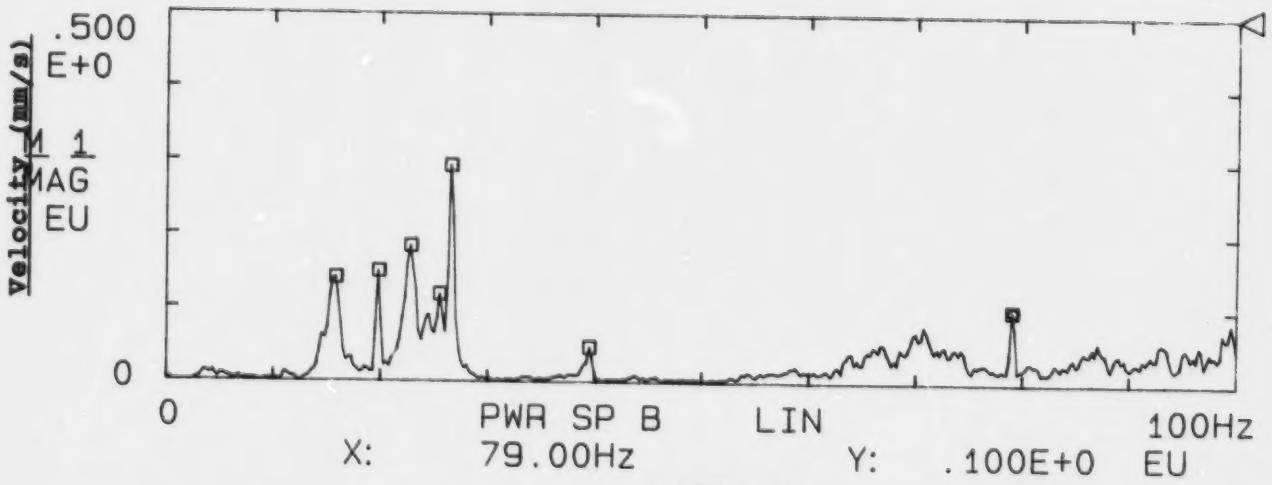


FIGURE 38
ECI RECOVERY PUMPSET #21 -PUMP STOOL VELOCITY (N-S DIRECTION) WITH ABSORBER

15:18

87-301

BRUCE GSA ECI REC P#21 PUMP STOOL AXI W/ABS VEL 03:30
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	15.50Hz	.956E-1	EU
2	19.75	.588E-1	
3	23.25	.125E+0	
4	43.75	.199E+0	
5	79.00	.215E+0	
6			
7			
8			
9			
10			

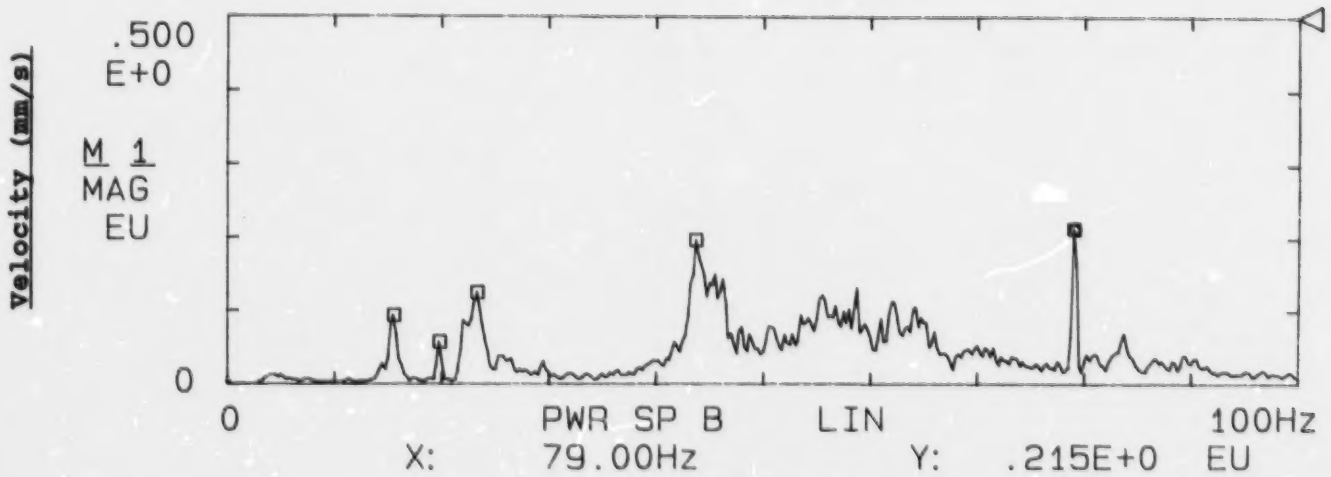


FIGURE 39
ECI RECOVERY PUMPSET #21 -PUMP STOOL VELOCITY (AXIAL DIRECTION) WITH ABSORBER

15:23

87-301

BRUCE GSA ECI REC P#22 MOTOR TOP E-W VEL NO ABS 01:40
100Hz A: AC/ 50V B: AC/ 50V S. SUM 8/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	16.25Hz	.153E+0	EU
2	19.75	.306E+1	
3	37.25	.612E+0	
4	40.00	.544E+0	
5	44.00	.968E-1	
6	50.25	.262E+0	
7	78.00	.102E+0	
8	79.00	.557E-1	
9			
10			

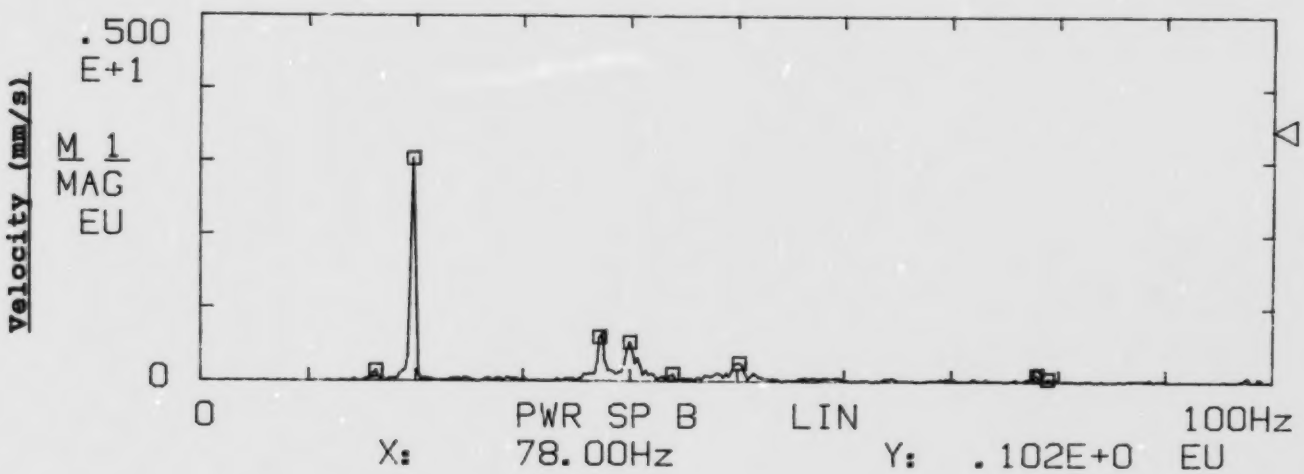


FIGURE 40
ECI RECOVERY PUMPSET #22 -TOP OF MOTOR CASING VELOCITY (E-W DIRECTION) WITHOUT ABSORBER

07:35

87-301

BRUCE GSA ECI REC P#22 MOTOR TOP N-S VEL NO ABS 01:44
100Hz A: AC/ 50V B: AC/ 50V S. SUM 8/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	17.00Hz	.740E+0	EU
2	19.75	.721E+0	
3	28.75	.394E+0	
4	30.00	.220E+0	
5	37.25	.260E+0	
6	79.00	.856E-1	
7			
8			
9			
10			

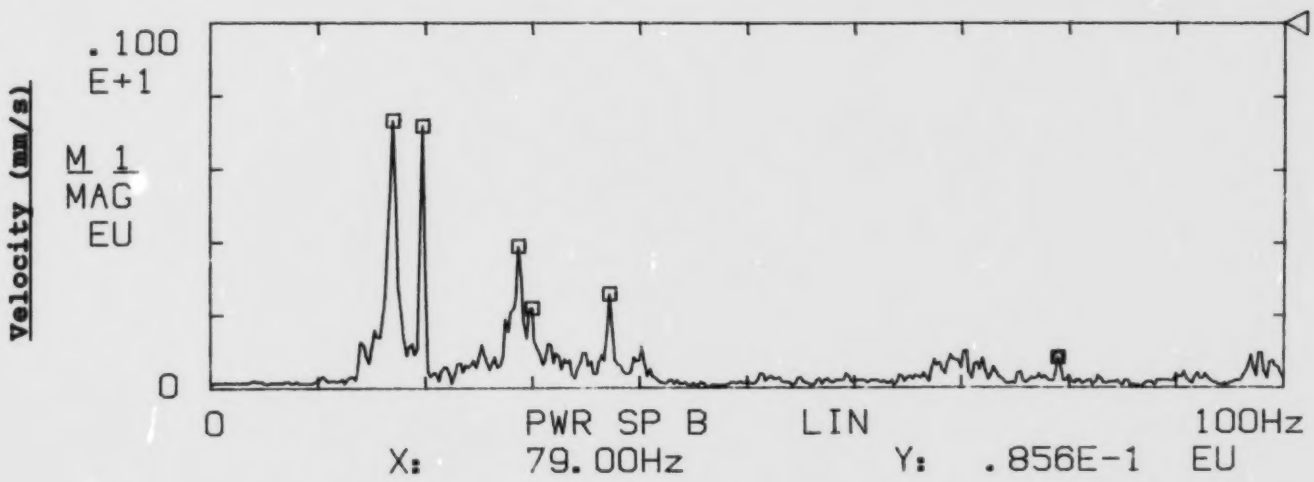


FIGURE 41
ECI RECOVERY PUMPSET #22 -TOP OF MOTOR CASING VELOCITY (N-S DIRECTION) WITHOUT ABSORBER

07:37

BRUCE GSA ECI REC P#22 MOTOR TOP AXI VEL NO ABS 01:47
100Hz A: AC/ 50V B: AC/ 50V S. SUM 8/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	16.75Hz	.937E-1	EU
2	19.75	.700E-1	
3	44.50	.292E+0	
4	45.75	.457E+0	
5	52.25	.259E+0	
6	55.50	.319E+0	
7	79.00	.566E+0	
8			
9			
10			

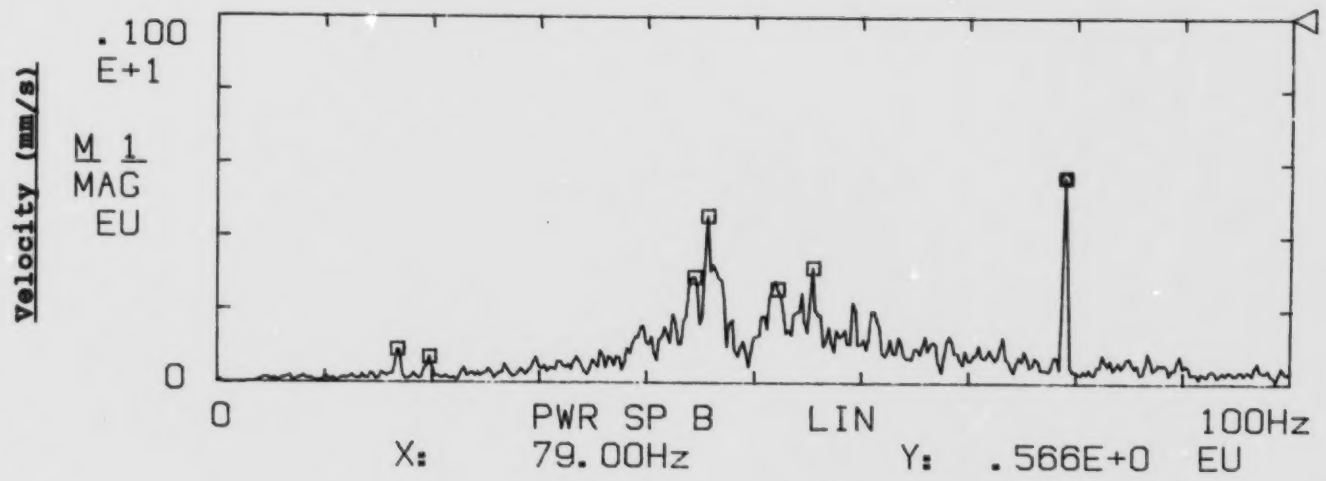


FIGURE 42
ECI RECOVERY PUMPSET #22 -TOP OF MOTOR CASING VELOCITY (AXIAL DIRECTION) WITHOUT ABSORBER

07:43

BRUCE GSA ECI REC P#22 MOTOR BOT E-W VEL NO ABS 01:56
100Hz A: AC/ 50V B: AC/ 50V S. SUM 8/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	19.75Hz	.274E+1	EU
2	40.00	.809E-1	
3			
4			
5			
6			
7			
8			
9			
10			

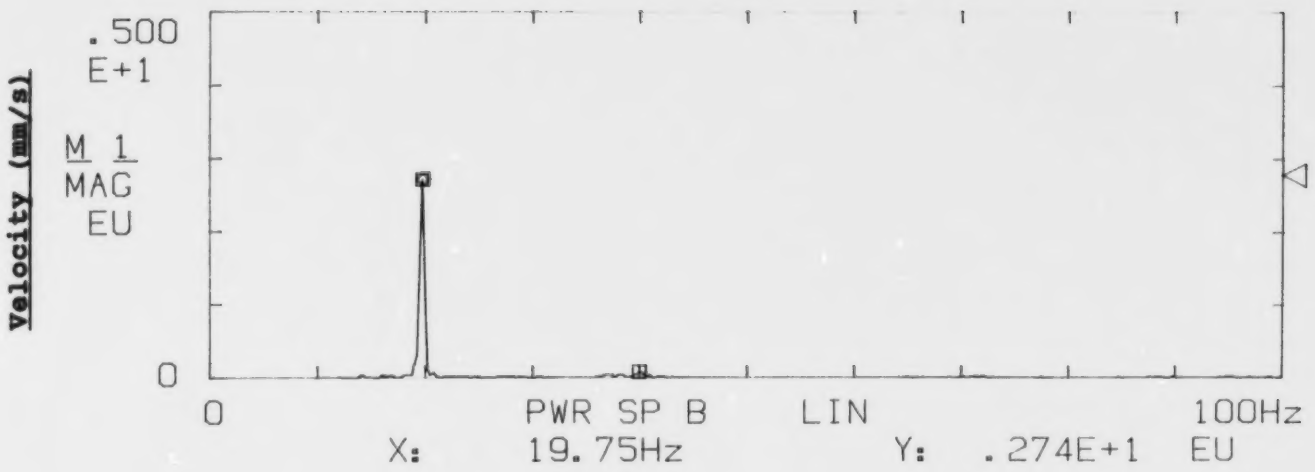


FIGURE 43
ECI RECOVERY PUMPSET #22 -BOTTOM OF MOTOR CASING VELOCITY (E-W DIRECTION) WITHOUT ABSORBER

07:47

87-301

BRUCE GSA ECI REC P#22 MOTOR BOT N-S VEL NO ABS 01:59
100Hz A: AC/ 50V B: AC/ 50V S. SUM 8/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	14.50Hz	.157E+0	EU
2	17.00	.631E+0	
3	19.75	.798E+0	
4	28.50	.277E+0	
5	29.50	.280E+0	
6	37.25	.219E+0	
7	79.00	.346E-1	
8			
9			
10			

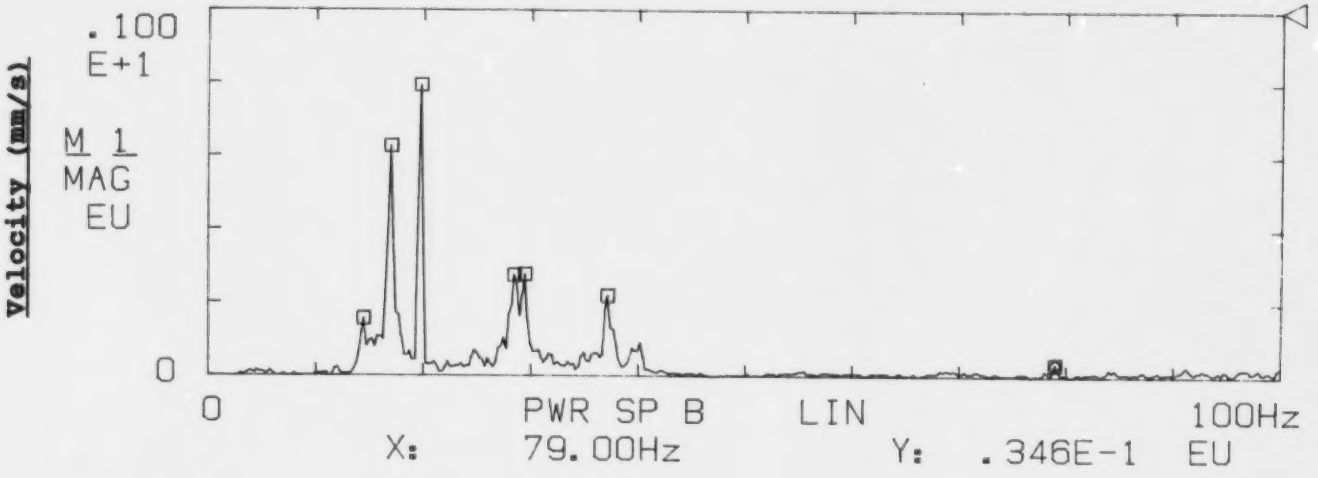


FIGURE 44
ECI RECOVERY PUMPSET #22 -BOTTOM OF MOTOR CASING VELOCITY (N-S DIRECTION) WITHOUT ABSORBER

07:48

BRUCE GSA ECI REC P#22 PUMP STOOL E-W NO ABS VEL 02:06
100Hz A: AC/ 50V B: AC/ 50V S. SUM 8/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	16.25Hz	.165E+0	EU
2	19.75	.201E+1	
3	39.50	.474E-1	
4	79.00	.681E-1	
5			
6			
7			
8			
9			
10			

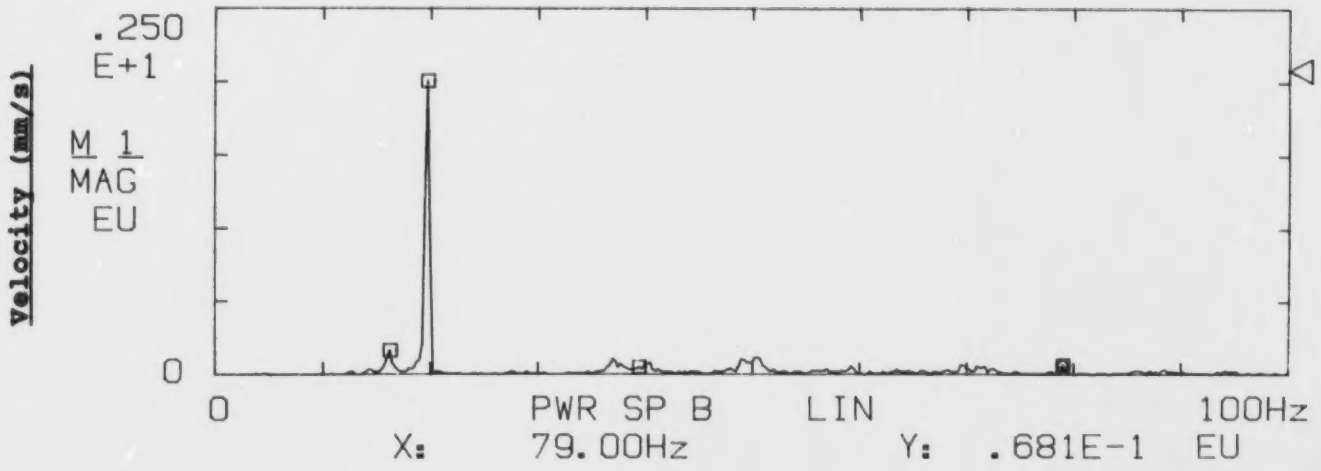


FIGURE 45
ECI RECOVERY PUMPSET #22 -PUMP STOOL VELOCITY (E-W DIRECTION) WITHOUT ABSORBER

07:53

87-301

BRUCE GSA ECI REC P#22 PUMP STOOL N-S NO ABS VEL 02:04
100Hz A: AC/ 50V B: AC/ 50V S. SUM 8/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	17.00Hz	.150E+0	EU
2	19.75	.243E+0	
3	28.75	.129E+0	
4	39.50	.131E-1	
5	69.50	.137E+0	
6	71.75	.117E+0	
7	79.00	.500E-1	
8			
9			
10			

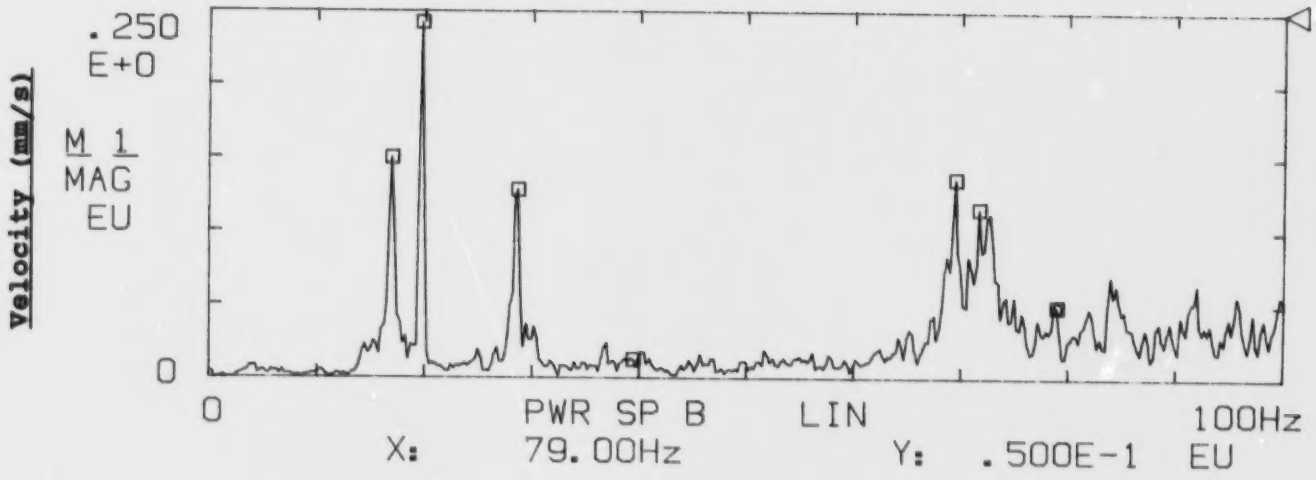


FIGURE 46
ECI RECOVERY PUMPSET #22 -PUMP STOOL VELOCITY (N-S DIRECTION) WITHOUT ABSORBER

07:51

BRUCE GSA ECI REC P#22 PUMP STOOL AXI NO ABS VEL 02:08
100Hz A: AC/ 50V B: AC/ 50V S. SUM 8/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	19.75Hz	.272E+0	EU
2	39.50	.504E-1	
3	45.25	.173E+0	
4	57.25	.334E+0	
5	59.25	.300E+0	
6	69.75	.257E+0	
7	79.00	.159E+0	
8			
9			
10			

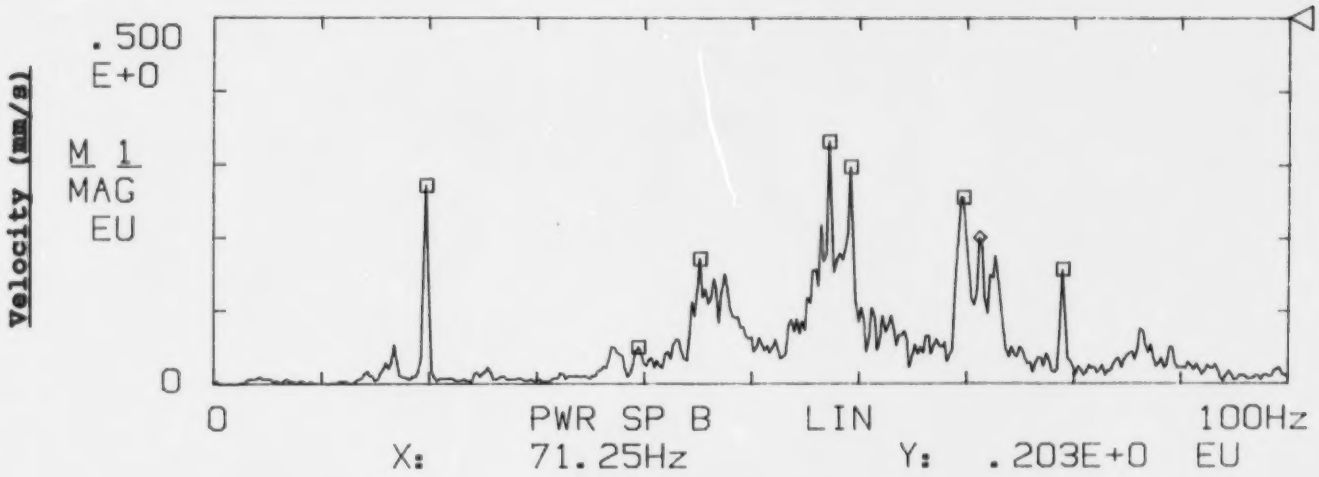


FIGURE 47
ECI RECOVERY PUMPSET #22 -PUMP STOOL VELOCITY (AXIAL DIRECTION) WITHOUT ABSORBER

07:55

BRUCE GSA ECI REC P#22 MOTOR TOP E-W W/ABS VEL 05: 30
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	16.25Hz	.349E+0	EU
2	19.75	.672E-1	
3	22.50	.235E+0	
4	37.25	.550E+0	
5	39.50	.244E+0	
6	50.25	.243E+0	
7	59.25	.140E+0	
8	78.00	.166E+0	
9	79.25	.721E-1	
10			

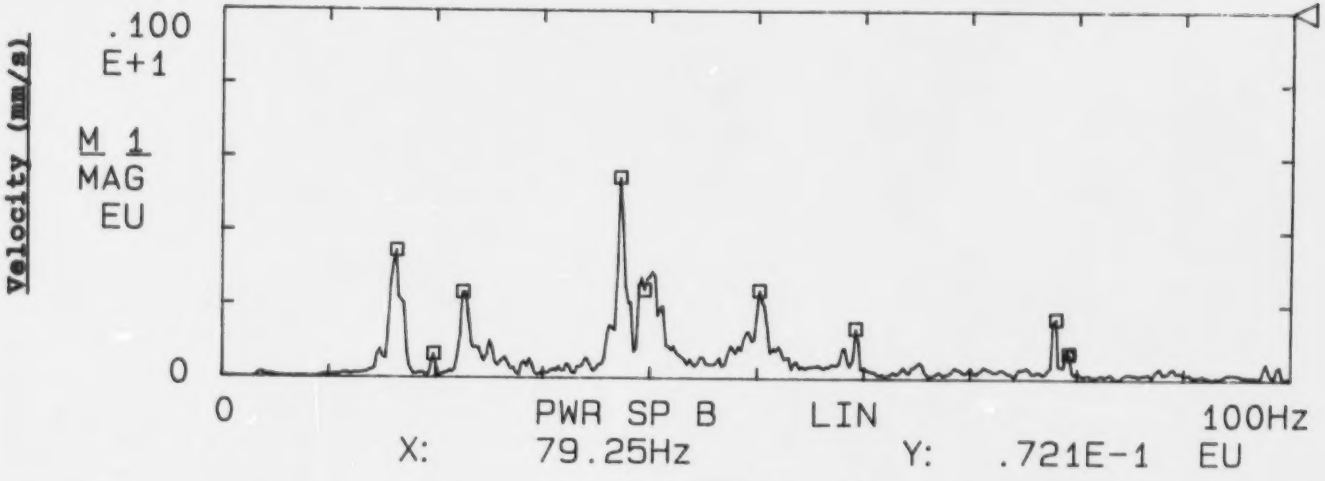


FIGURE 48
ECI RECOVERY PUMPSET #22 -TOP OF MOTOR CASING VELOCITY (E-W DIRECTION) WITH ABSORBER

15: 29

87-301

BRUCE GSA ECI REC P#22 MOTOR TOP N-S W/ABS VEL 05:34
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	16.50Hz	.610E+0	EU
2	19.75	.819E+0	
3	25.75	.755E+0	
4	39.50	.447E+0	
5			
6			
7			
8			
9			
10			

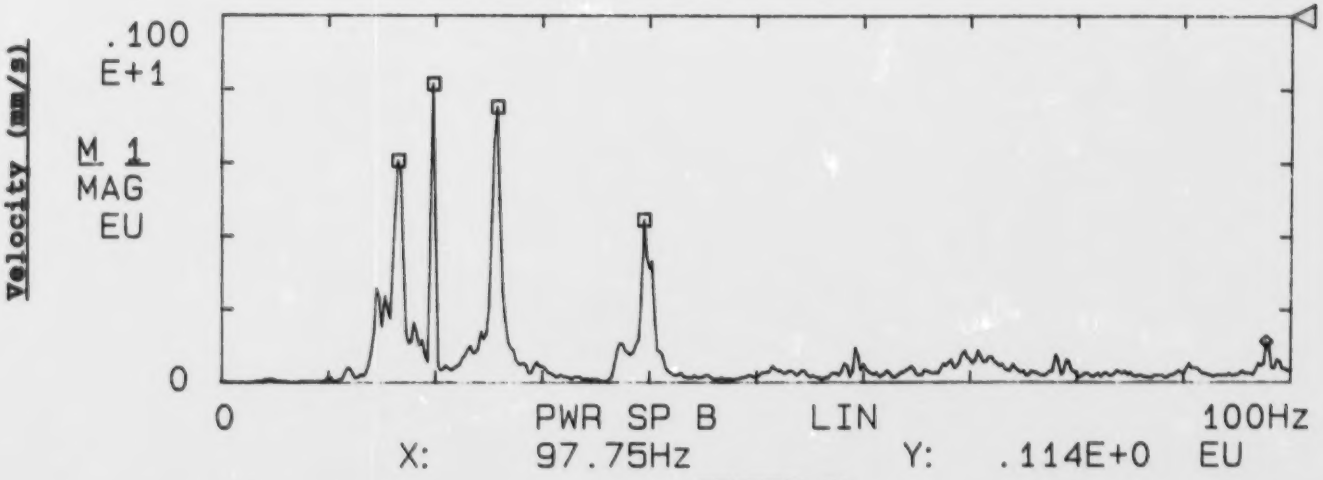


FIGURE 49
ECI RECOVERY PUMPSET #22 -TOP OF MOTOR CASING VELOCITY (N-S DIRECTION) WITH ABSORBER

87-301

15:31

BRUCE GSA ECI REC P#22 MOTOR TOP AXI W/ABS VEL 05: 37
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	45.00Hz	.697E+0	EU
2	55.00	.471E+0	
3	78.75	.572E+0	
4	120.00	.241E+0	
5	157.50	.329E+0	
6	280.00	.171E+0	
7			
8			
9			
10			

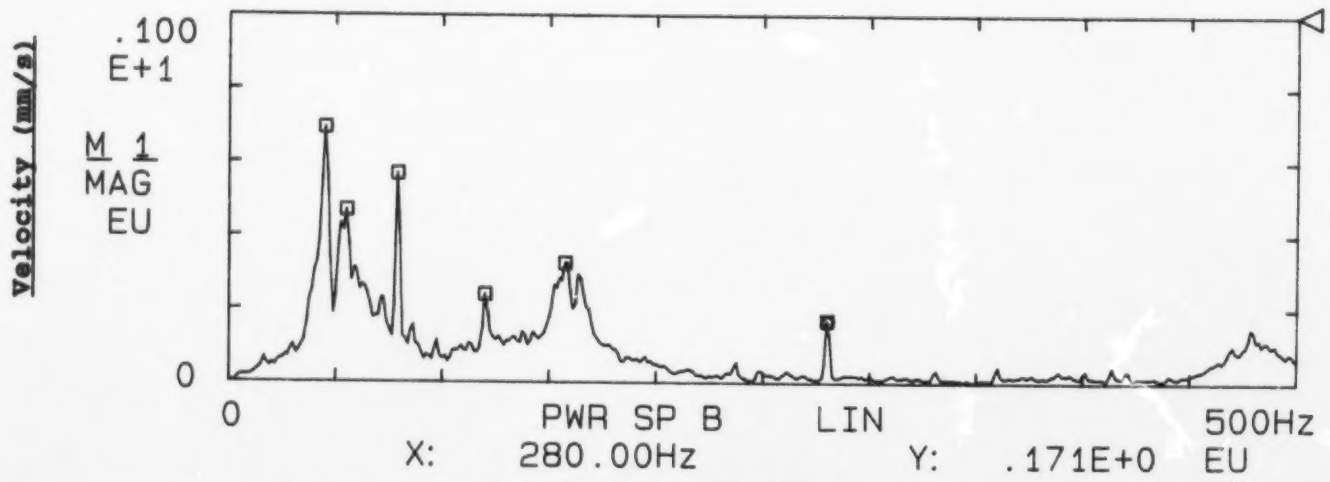


FIGURE 50
ECI RECOVERY PUMPSET #22 -TOP OF MOTOR CASING VELOCITY (AXIAL DIRECTION) WITH ABSORBER

15: 43

BRUCE GSA ECI REC P#22 MOTOR BOT E-W W/ABS VEL 05: 45
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	16.75Hz	.254E+0	EU
2	19.75	.200E+0	
3	22.75	.238E+0	
4	37.25	.722E-1	
5	39.50	.784E-1	
6	79.00	.317E-1	
7			
8			
9			
10			

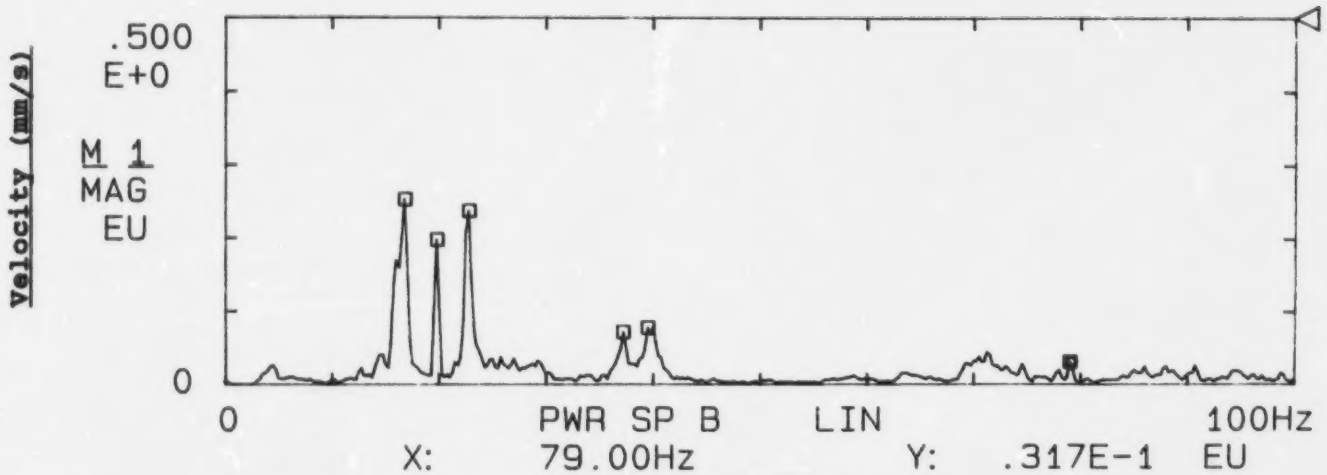


FIGURE 51
ECI RECOVERY PUMPSET #22 -BOTTOM OF MOTOR CASING VELOCITY (E-W DIRECTION) WITH ABSORBER

15: 36

BRUCE GSA ECI REC P#22 MOTOR BOT N-S W/ABS VEL 05: 48
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	16.50Hz	.364E+0	EU
2	19.75	.498E+0	
3	25.75	.639E+0	
4	39.50	.274E+0	
5	40.00	.259E+0	
6			
7			
8			
9			
10			

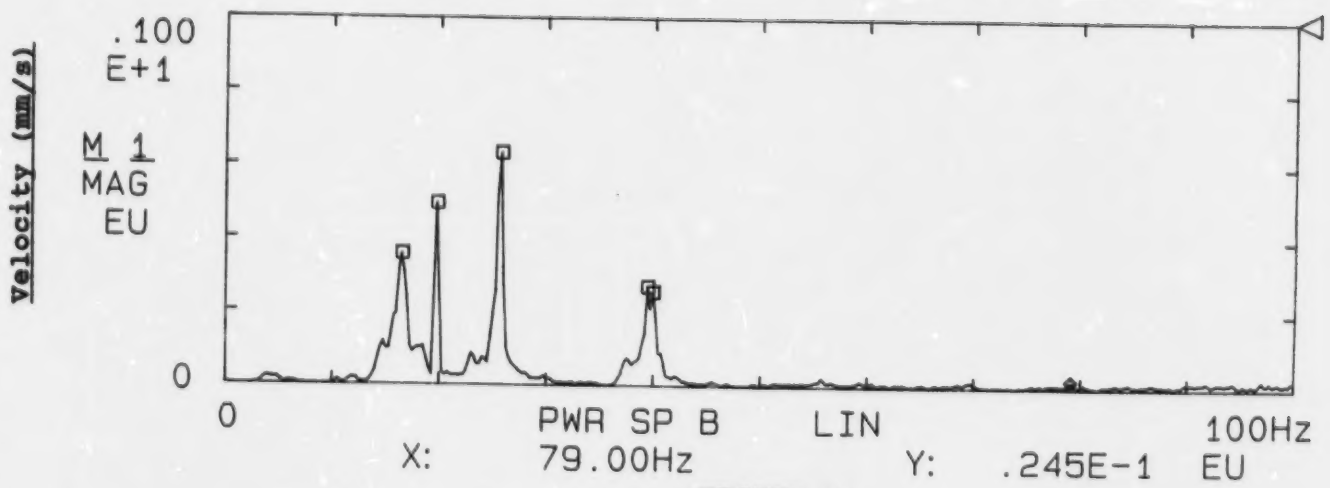


FIGURE 52
ECI RECOVERY PUMPSET #22 -BOTTOM OF MOTOR CASING VELOCITY (N-S DIRECTION) WITH ABSORBER

15: 41

BRUCE GSA ECI REC P#22 PUMP STOOL E-W W/ABS VEL 05:56
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	16.75Hz	.152E+0	EU
2	19.75	.300E+0	
3	22.75	.163E+0	
4	37.25	.163E+0	
5	39.50	.870E-1	
6	79.00	.714E-1	
7			
8			
9			
10			

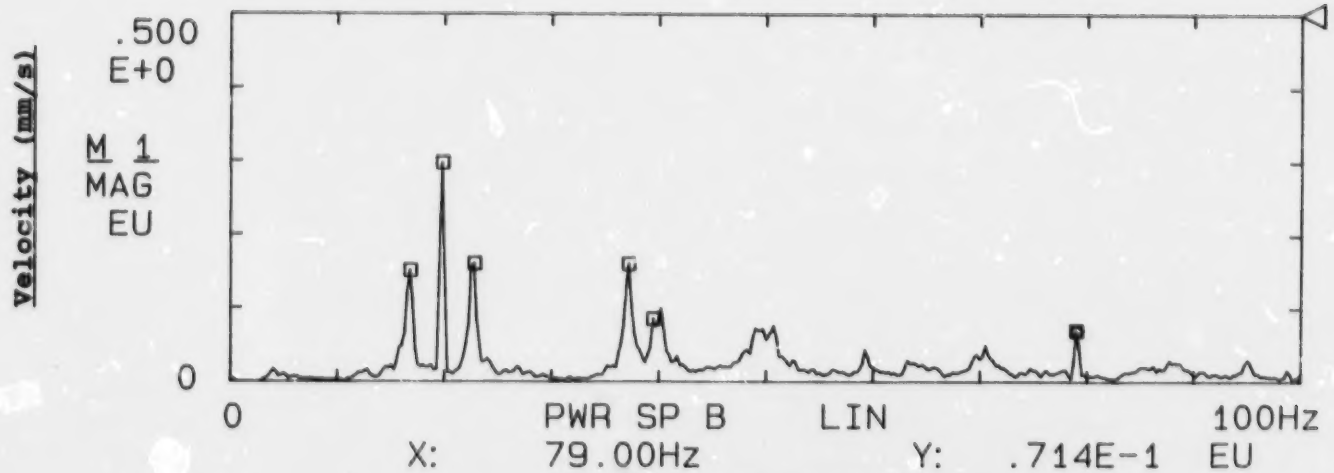


FIGURE 53
ECI RECOVERY PUMPSET #22 -PUMP STOOL VELOCITY (E-W DIRECTION) WITH ABSORBER

87-301

15:52

BRUCE GSA ECI REC P#22 PUMP STOOL N-S W/ABS VEL 05:54
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	16.50Hz	.107E+0	EU
2	19.75	.132E+0	
3	25.75	.132E+0	
4	39.50	.903E-1	
5	79.00	.100E+0	
6			
7			
8			
9			
10			

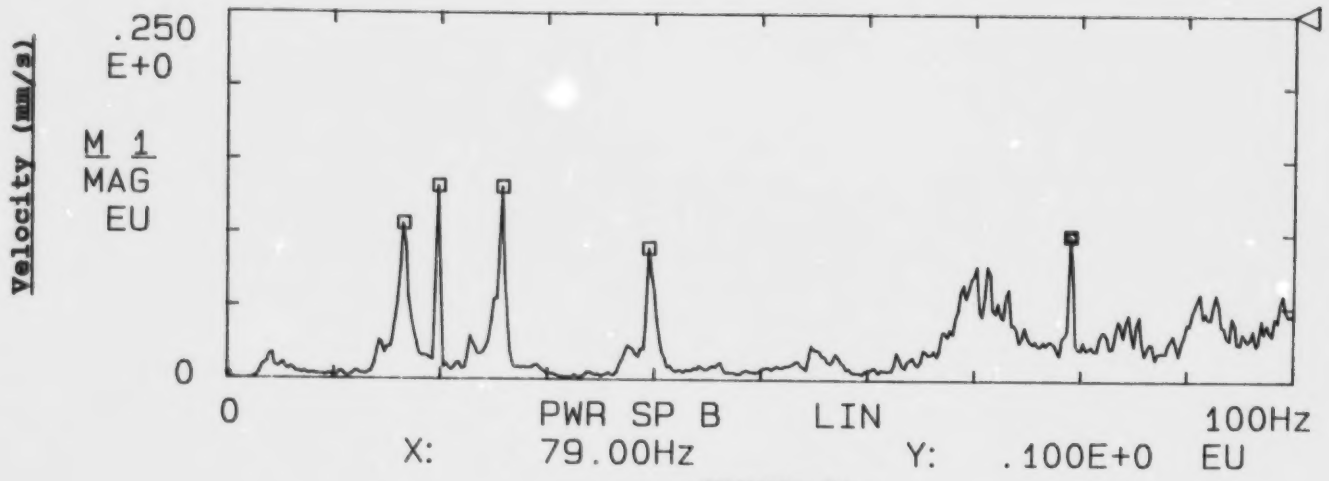


FIGURE 54
ECI RECOVERY PUMPSET #22 -PUMP STOOL VELOCITY (N-S DIRECTION) WITH ABSORBER

15:50

87-301

BRUCE GSA ECI REC P#22 PUMP STOOL AXI W/ABS VEL 05:58
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	16.00Hz	.744E-1	EU
2	19.50	.450E-1	
3	37.00	.649E-1	
4	46.50	.250E+0	
5	58.00	.263E+0	
6	70.00	.127E+0	
7	79.00	.191E+0	
8	86.00	.740E-1	
9	120.00	.131E+0	
10	158.00	.121E+0	

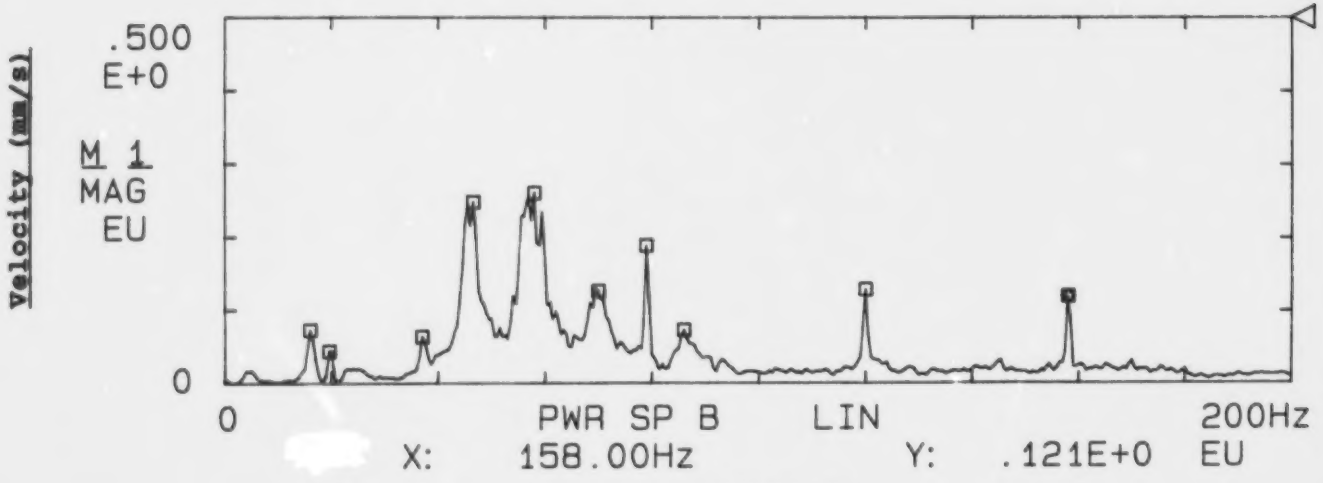


FIGURE 55
ECI RECOVERY PUMPSET #22 -PUMP STOOL VELOCITY (AXIAL DIRECTION) WITH ABSORBER

16:00

VELOCITY T OF M E-W BRUCE NGSA ECIS PUMP#23 01: 15
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChA	
1	15.50Hz	.523E+0	EU
2	19.75	.715E+1	
3	22.25	.127E+1	
4	79.00	.736E+0	
5			
6			
7			
8			
9			
10			

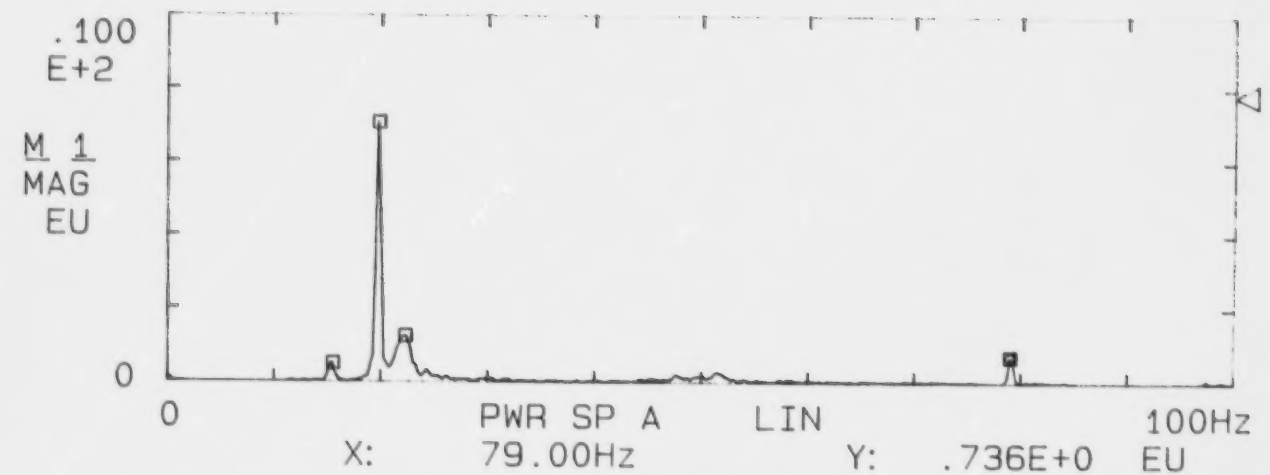


FIGURE 56
ECI RECOVERY PUMPSET #23 -TOP OF MOTOR CASING VELOCITY (E-W DIRECTION) WITHOUT ABSORBER

01: 01

87-301

VELOCITY T OF M N-S BRUCE NGSA ECIS PUMP#23 01:18
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChA	
1	16.00Hz	.104E+1	EU
2	19.75	.176E+1	
3	21.25	.637E+0	
4	23.00	.116E+1	
5	24.75	.815E+0	
6	30.75	.121E+1	
7	79.00	.296E+0	
8			
9			
10			

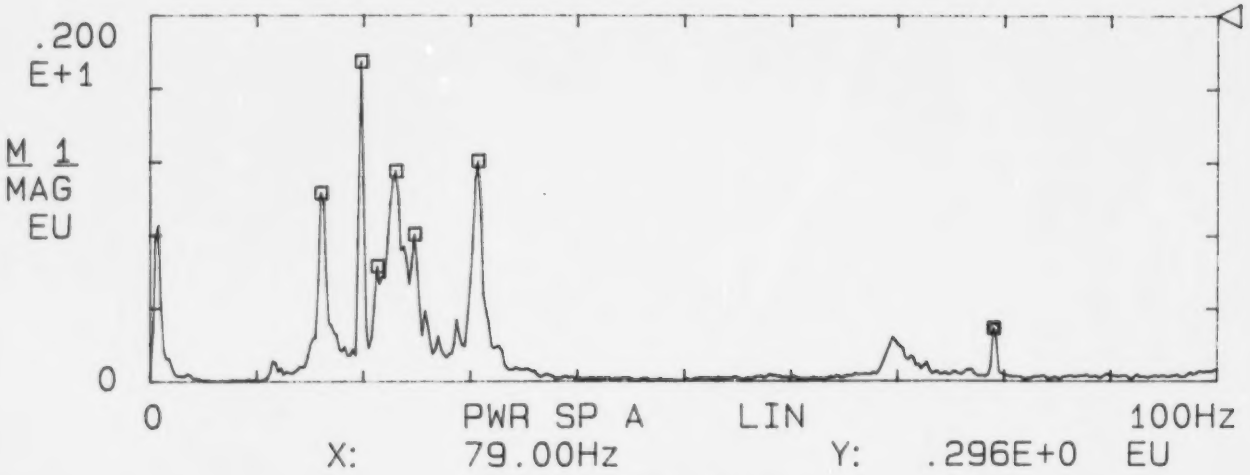


FIGURE 57
ECI RECOVERY PUMPSET #23 -TOP OF MOTOR CASING VELOCITY (N-S DIRECTION) WITHOUT ABSORBER

01:05

VELOCITY B OF M E-W BRUCE NGSA ECIS PUMP#23 01:52
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChA	
1	19.75Hz	.514E+1	EU
2	22.00	.593E+0	
3	79.00	.250E+0	
4			
5			
6			
7			
8			
9			
10			

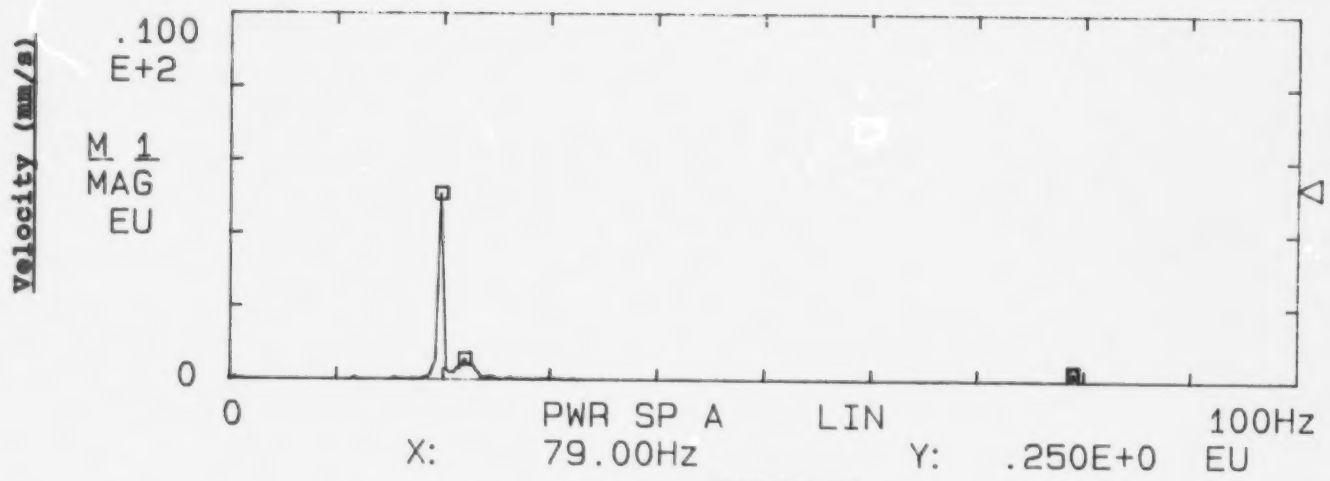


FIGURE 58
ECI RECOVERY PUMPSET #23 -BOTTOM OF MOTOR CASING VELOCITY (E-W DIRECTION) WITHOUT ABSORBER

01:09

87-301

VELOCITY B OF M N-S BRUCE NGSA ECIS PUMP#23 01:48
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChA	
1	16.00Hz	.783E+0	EU
2	19.75	.971E+0	
3	22.75	.647E+0	
4	24.25	.523E+0	
5	30.50	.721E+0	
6			
7			
8			
9			
10			

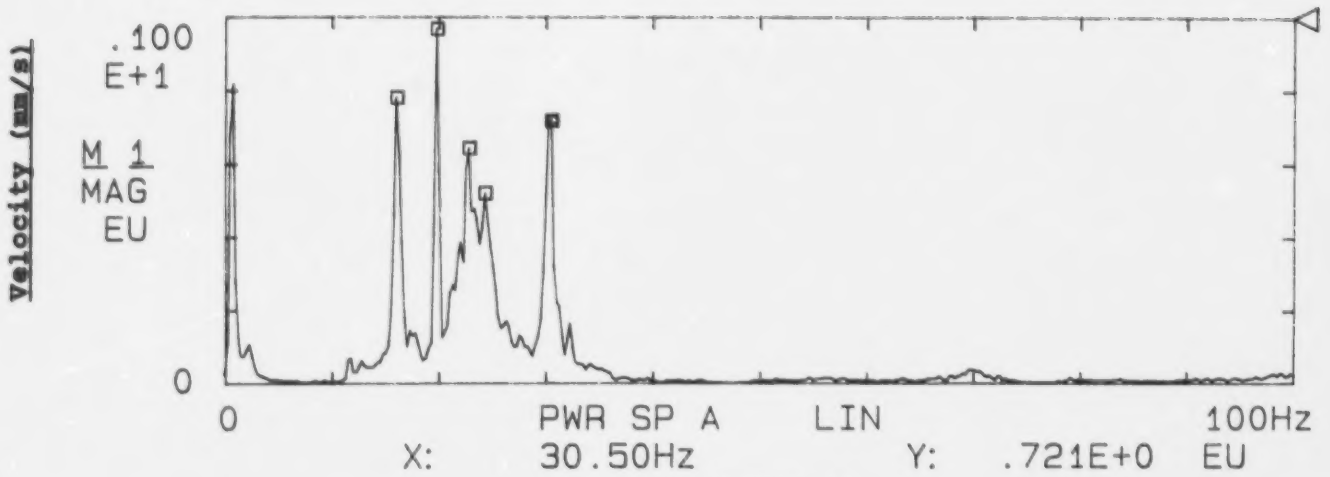


FIGURE 59
ECI RECOVERY PUMPSET #23 -BOTTOM OF MOTOR CASING VELOCITY (N-S DIRECTION) WITHOUT ABSORBER

01:07

87-301

BRUCE GSA ECI REC P#23 MOTOR TOP E-W W/ABS VEL 06: 17
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	15.50Hz	.872E+0	EU
2	16.50	.711E+0	
3	19.75	.206E+0	
4	22.00	.100E+1	
5	23.00	.183E+1	
6	39.50	.234E-1	
7	46.50	.180E+0	
8	50.75	.221E+0	
9	79.00	.376E+0	
10			

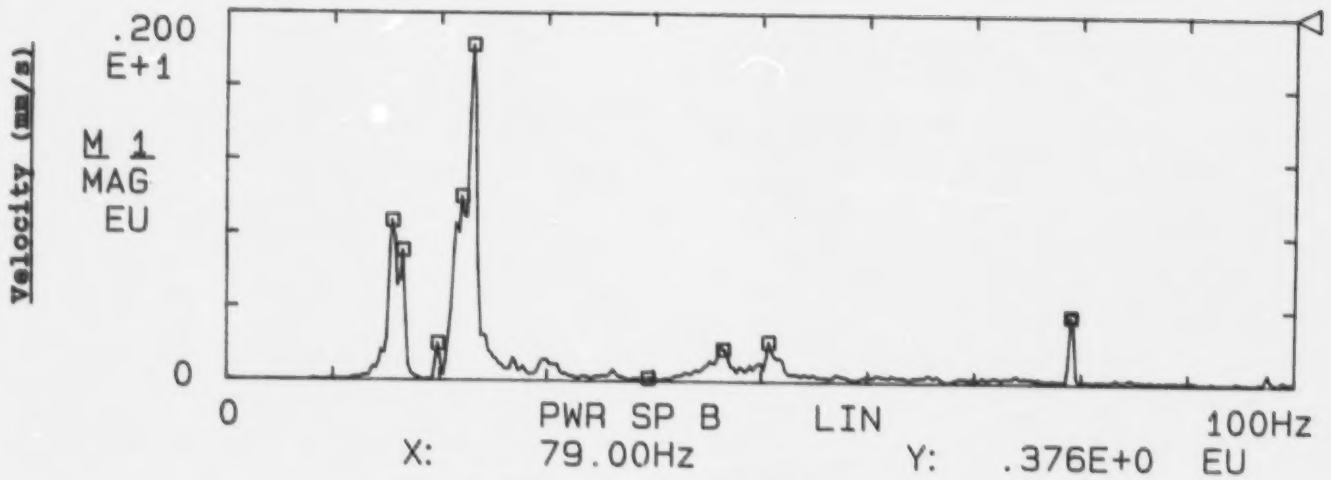


FIGURE 60
ECI RECOVERY PUMPSET #23 -TOP OF MOTOR CASING VELOCITY (E-W DIRECTION) WITH ABSORBER

16: 02

87-301

BRUCE GSA ECI REC P#23 MOTOR TOP N-S W/ABS VEL 06: 19
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	15.75Hz	.165E+1	EU
2	19.75	.214E+1	
3	21.25	.114E+1	
4	22.00	.162E+1	
5	24.75	.737E+0	
6	26.75	.179E+1	
7	39.75	.145E+0	
8	79.00	.205E+0	
9			
10			

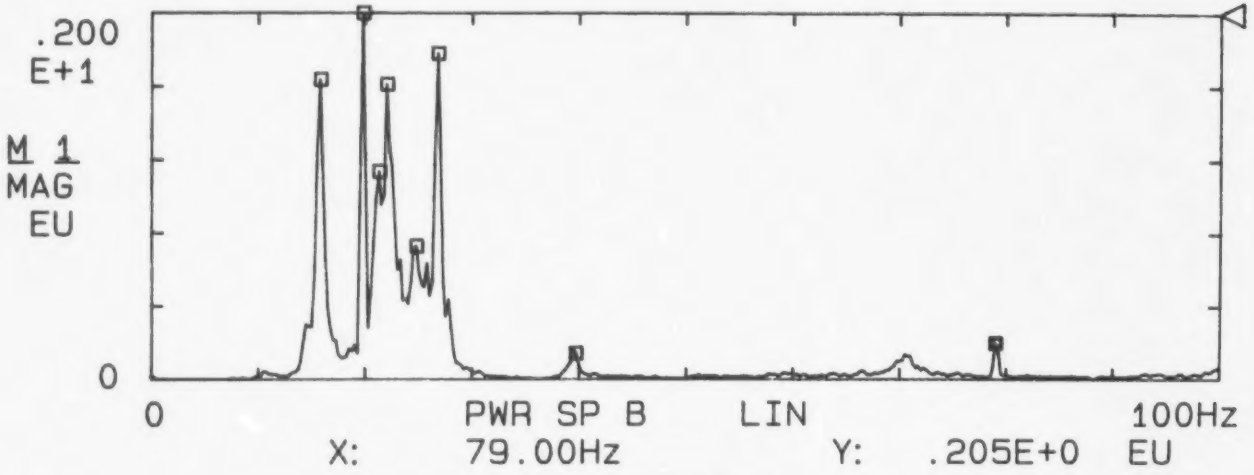


FIGURE 61
ECI RECOVERY PUMPSET #23 -TOP OF MOTOR CASING VELOCITY (N-S DIRECTION) WITH ABSORBER

16: 04

87-301

BRUCE GSA ECI REC P#23 MOTOR TOP AXI W/ABS VEL 06: 21
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	19.50Hz	.834E-1	EU
2	45.00	.567E+0	
3	59.00	.382E+0	
4	79.00	.886E+0	
5	158.00	.767E+0	
6			
7			
8			
9			
10			

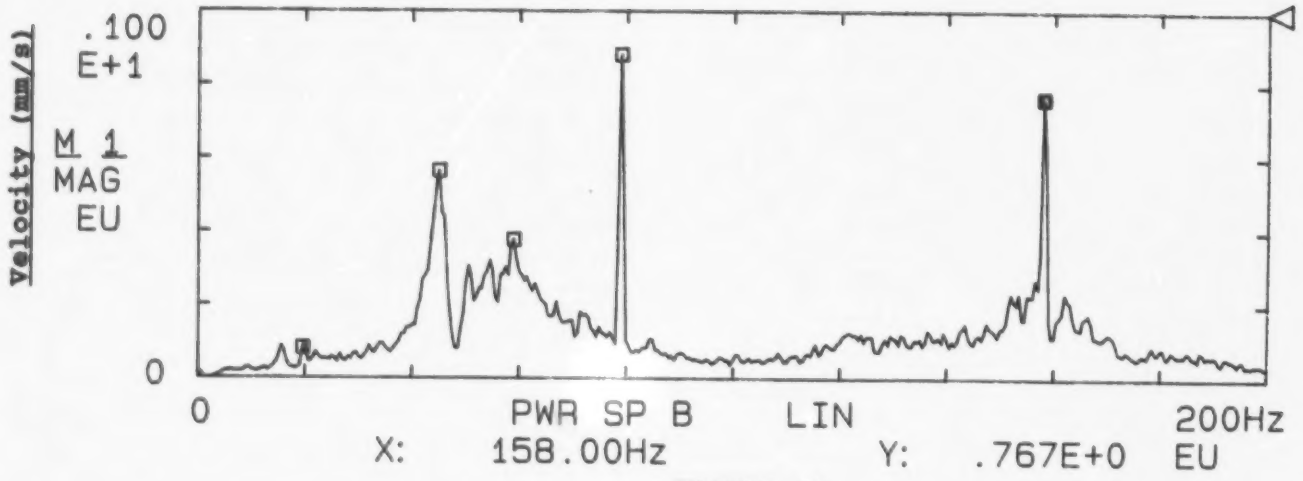


FIGURE 62
ECI RECOVERY PUMPSET #23 -TOP OF MOTOR CASING VELOCITY (AXIAL DIRECTION) WITH ABSORBER

16: 13

87-301

BRUCE GSA ECI REC P#23 MOTOR BOT E-W W/ABS VEL 06: 28
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	15.50Hz	.436E+0	EU
2	16.50	.440E+0	
3	19.75	.496E+0	
4	22.00	.121E+1	
5	23.00	.112E+1	
6	30.00	.883E-1	
7	79.00	.186E+0	
8			
9			
10			

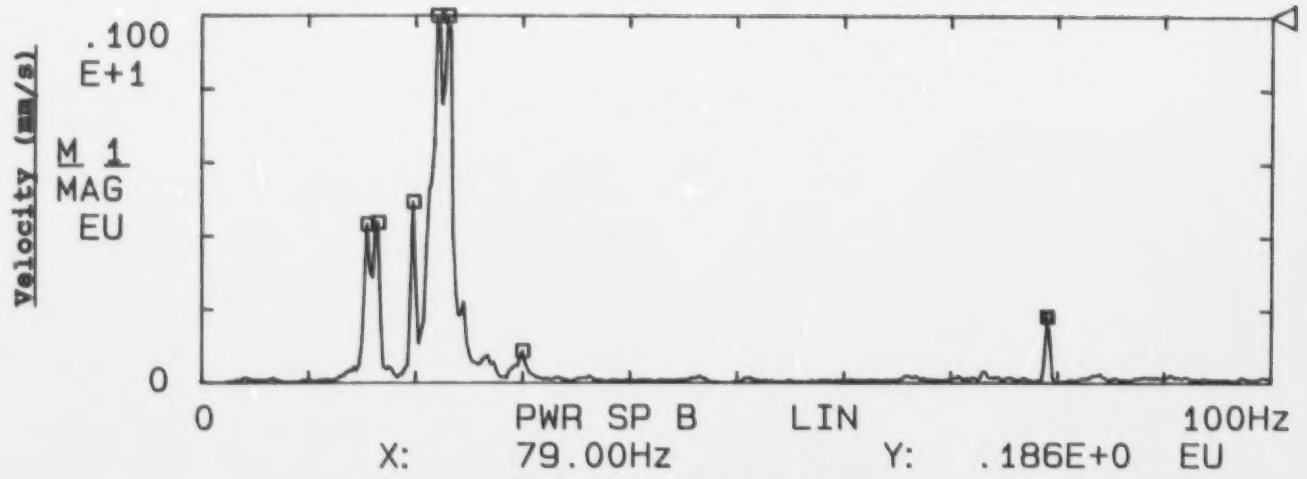


FIGURE 63
ECI RECOVERY PUMPSET #23 -BOTTOM OF MOTOR CASING VELOCITY (E-W DIRECTION) WITH ABSORBER

16: 16

BRUCE GSA ECI REC P#23 MOTOR BOT N-S W/ABS VEL 06: 30
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	15.75Hz	.110E+1	EU
2	19.75	.117E+1	
3	22.25	.871E+0	
4	26.75	.838E+0	
5	39.75	.121E+0	
6			
7			
8			
9			
10			

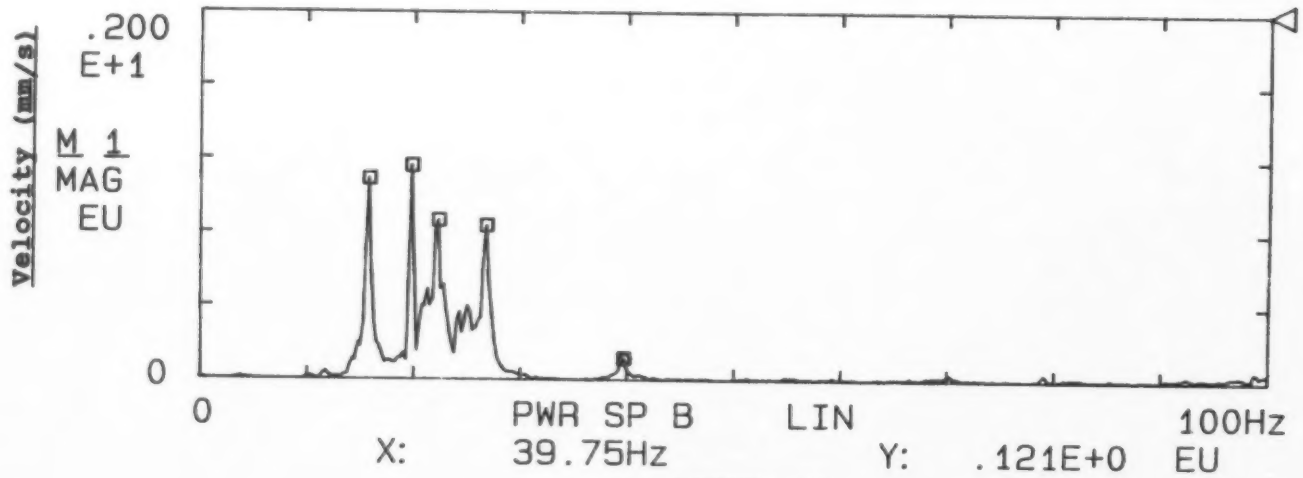


FIGURE 64
ECI RECOVERY PUMPSET #23 -BOTTOM OF MOTOR CASING VELOCITY (N-S DIRECTION) WITH ABSORBER

16: 19

BRUCE GSA ECI REC P#23 PUMP STOOL E-W W/ABS VEL 06:37
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	16.50Hz	.411E+0	EU
2	19.75	.837E+0	
3	22.00	.775E+0	
4	23.00	.759E+0	
5	39.50	.683E-2	
6	79.00	.270E+0	
7			
8			
9			
10			

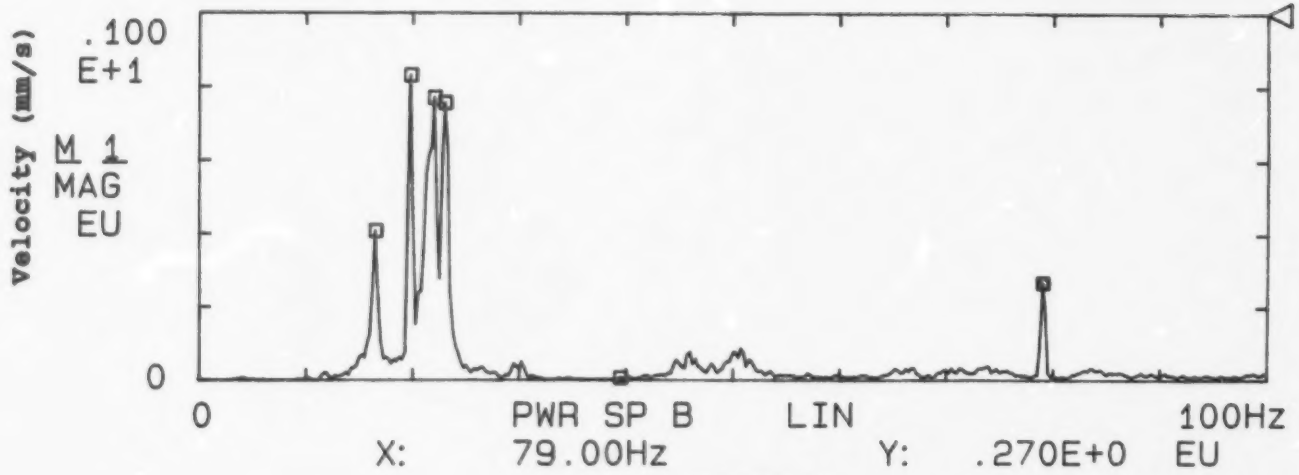


FIGURE 65
ECI RECOVERY PUMPSET #23 -PUMP STOOL VELOCITY (E-W DIRECTION) WITH ABSORBER

16: 29

BRUCE GSA ECI REC P#23 PUMP STOOL N-S W/ABS VEL 06: 36
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	15.75Hz	.148E+0	EU
2	19.75	.353E+0	
3	22.00	.204E+0	
4	26.50	.177E+0	
5	39.50	.301E-1	
6	70.25	.232E+0	
7	79.00	.246E+0	
8			
9			
10			

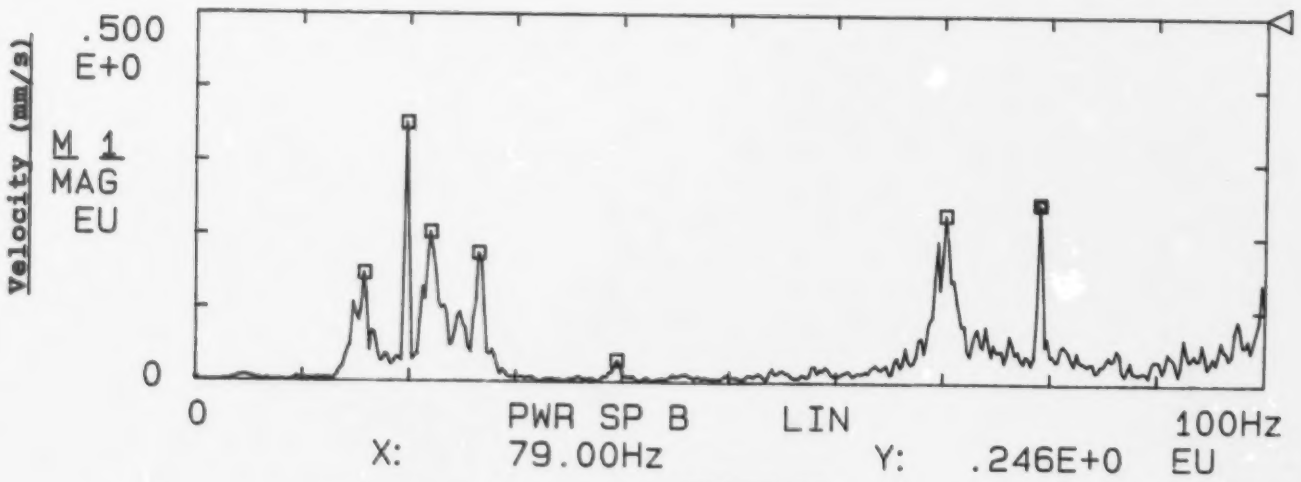


FIGURE 66
ECI RECOVERY PUMPSET #23 -PUMP STOOL VELOCITY (N-S DIRECTION) WITH ABSORBER

16: 22

87-301

BRUCE GSA ECI REC P#23 PUMP STOOL AXI W/ABS VEL 06: 39
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	15.25Hz	.194E+0	EU
2	19.75	.107E+0	
3	23.00	.272E+0	
4	45.00	.211E+0	
5	58.50	.206E+0	
6	70.25	.182E+0	
7	79.00	.336E+0	
8			
9			
10			

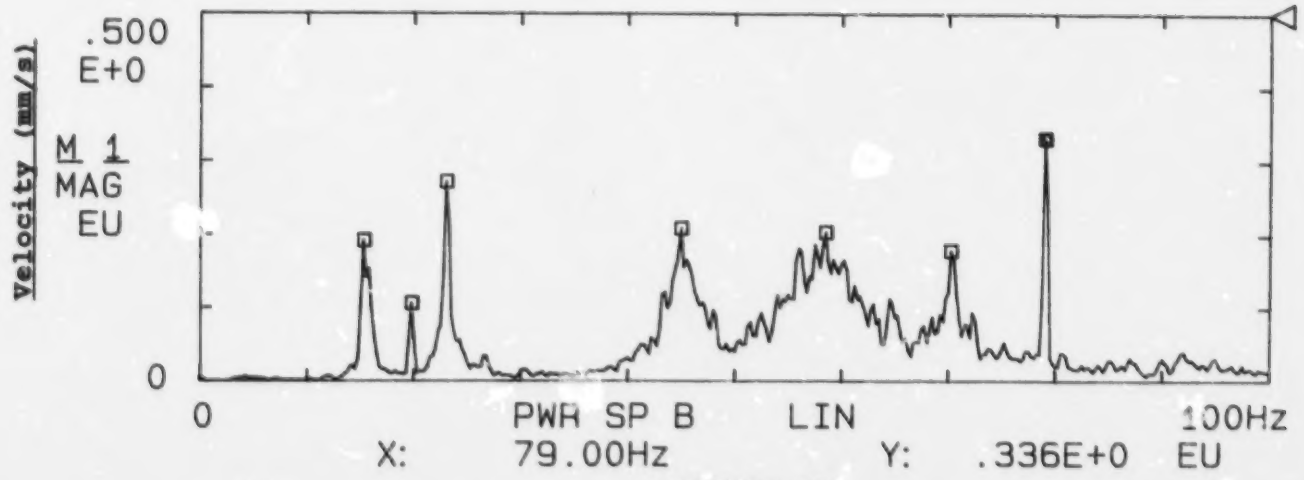


FIGURE 67
ECI RECOVERY PUMPSET #23 -PUMP STOOL VELOCITY (AXIAL DIRECTION) WITH ABSORBER

16: 27

87-301

BRUCE GSA ECI REC P#24 MOTOR TOP E-W VEL NO ABS 02:33
100Hz A: AC/ 50V B: AC/ 50V S. SUM 8/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	18.75Hz	.581E+0	EU
2	19.75	.231E+1	
3	36.50	.486E+0	
4	39.50	.888E-1	
5	41.50	.440E+0	
6	48.75	.324E+0	
7			
8			
9			
10			

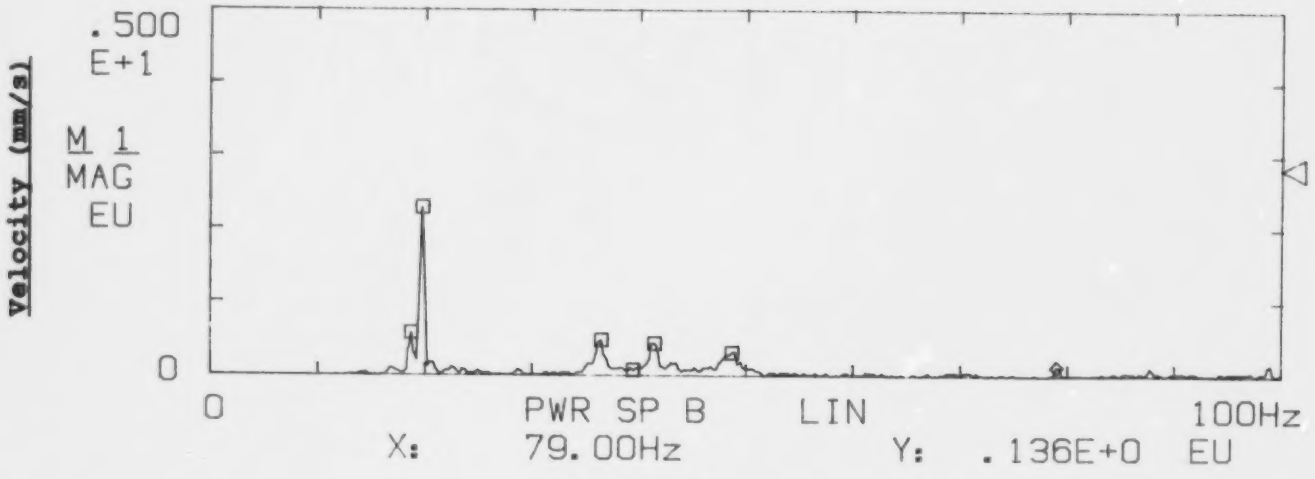


FIGURE 68
ECI RECOVERY PUMPSET #24 -TOP OF MOTOR CASING VELOCITY (E-W DIRECTION) WITHOUT ABSORBER

07:59

87-301

BRUCE GSA ECI REC P#24 MOTOR TOP N-S VEL NO ABS 02:38
100Hz A: AC/ 50V B: AC/ 50V S. SUM 8/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	16.75Hz	.990E+0	EU
2	19.75	.108E+1	
3	28.75	.142E+1	
4	39.50	.148E+0	
5	69.00	.146E+0	
6			
7			
8			
9			
10			

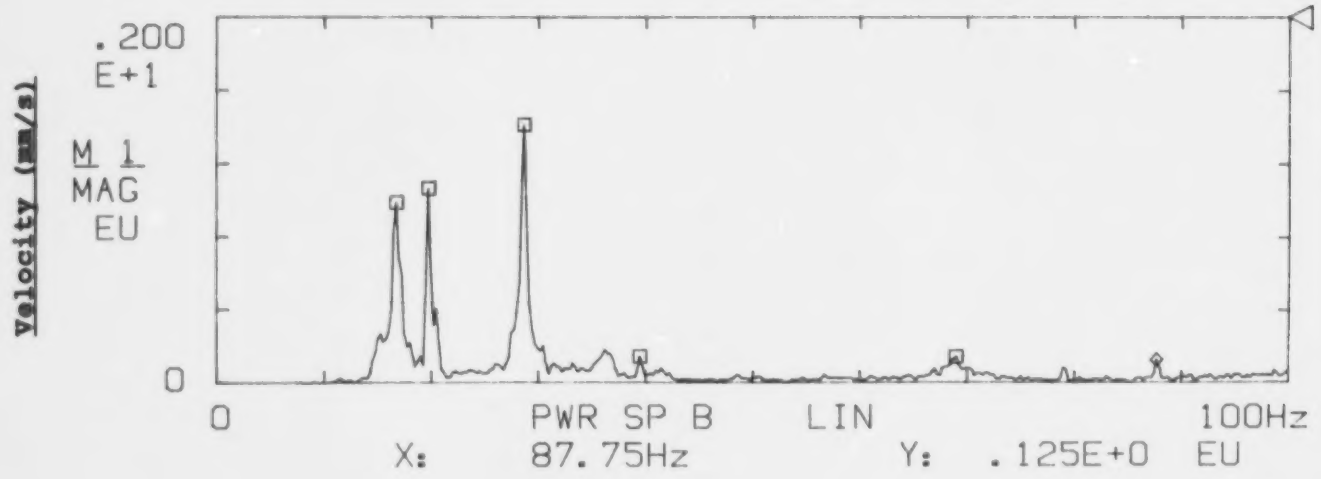


FIGURE 69
ECI RECOVERY PUMPSET #24 -TOP OF MOTOR CASING VELOCITY (N-S DIRECTION) WITHOUT ABSORBER

87-301
08:01

BRUCE GSA ECI REC P#24 MOTOR TOP AXI VEL NO ABS 02:42
100Hz A: AC/ 50V B: AC/ 50V S. SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	45.0Hz	.139E+1	EU
2	80.0	.904E+0	
3	155.0	.832E+0	
4	385.0	.298E+0	
5	580.0	.571E+0	
6	630.0	.651E+0	
7			
8			
9			
10			

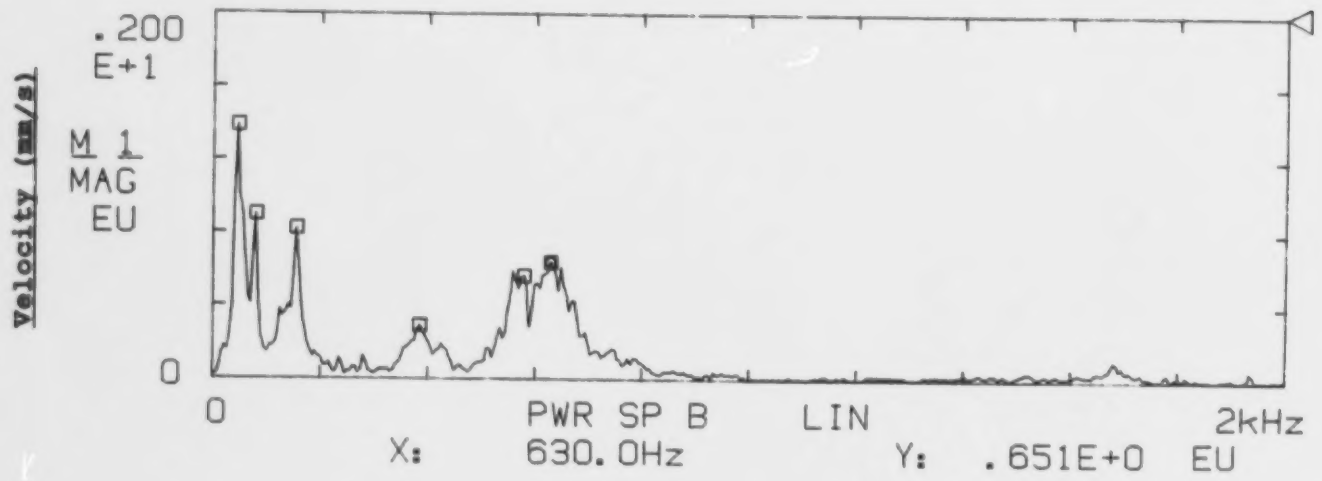


FIGURE 70
ECI RECOVERY PUMPSET #24 -TOP OF MOTOR CASING VELOCITY (AXIAL DIRECTION) WITHOUT ABSORBER

00:10

87-301

BRUCE GSA ECI REC P#24 MOTOR BOT E-W VEL NO ABS 02:45
100Hz A: AC/ 50V B: AC/ 50V S. SUM 8/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	15.25Hz	.142E+0	EU
2	18.75	.412E+0	
3	19.75	.762E+0	
4	36.75	.139E+0	
5	79.00	.300E+0	
6			
7			
8			
9			
10			

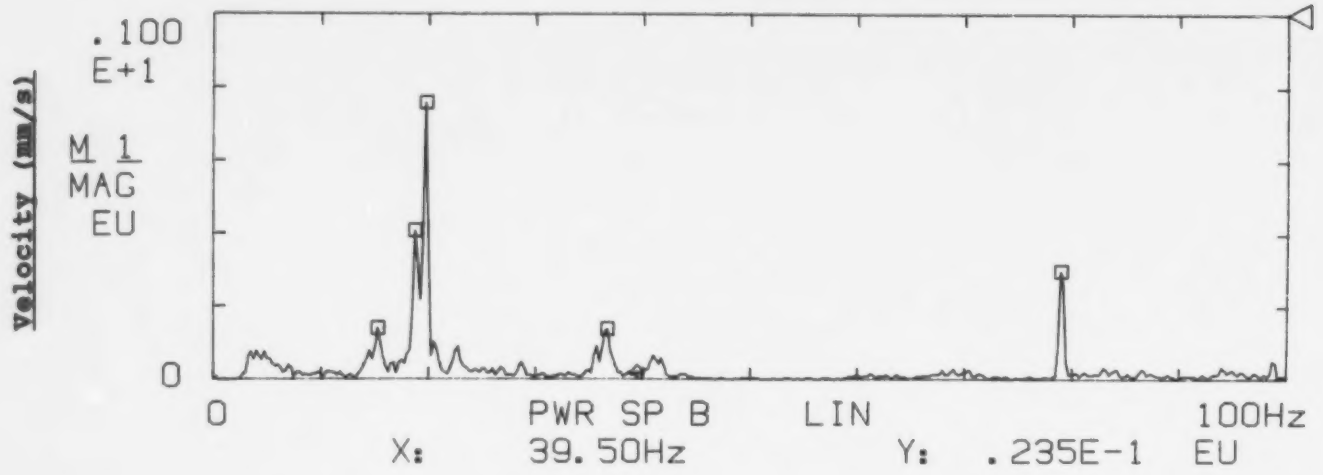


FIGURE 71
ECI RECOVERY PUMPSET #24 -BOTTOM OF MOTOR CASING VELOCITY (E-W DIRECTION) WITHOUT ABSORBER

08:04

87-301

BRUCE GSA ECI REC P#24 MOTOR BOT N-S VEL NO ABS 02:47
100Hz A: AC/ 50V B: AC/ 50V S. SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	14.50Hz	.157E+0	EU
2	16.75	.842E+0	
3	19.75	.438E+0	
4	29.00	.514E+0	
5	36.50	.151E+0	
6	39.50	.652E-1	
7	41.25	.116E+0	
8	79.00	.627E-1	
9			
10			

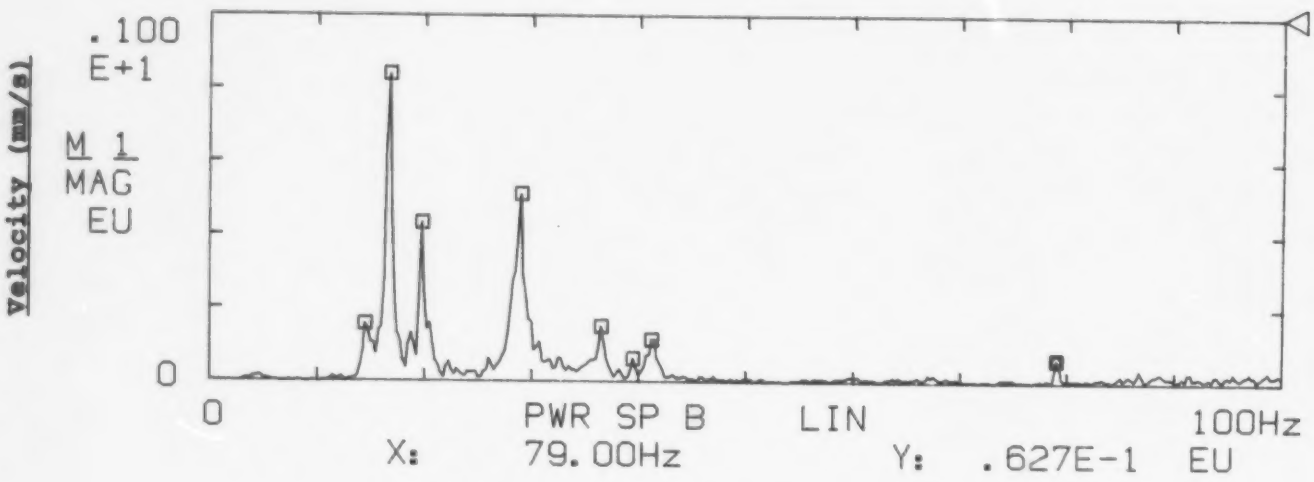


FIGURE 72
ECI RECOVERY PUMPSET #24 -BOTTOM OF MOTOR CASING VELOCITY (N-S DIRECTION) WITHOUT ABSORBER

00:13

BRUCE GSA ECI REC P#24 PUMP STOOL E-W NO ABS VEL 02:53
100Hz A: AC/ 50V B: AC/ 50V S. SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	15.50Hz	.255E+0	EU
2	19.00	.352E+0	
3	19.75	.204E+0	
4	22.75	.726E-1	
5	36.50	.137E+0	
6	39.50	.352E-1	
7	48.75	.154E+0	
8	79.00	.550E+0	
9			
10			

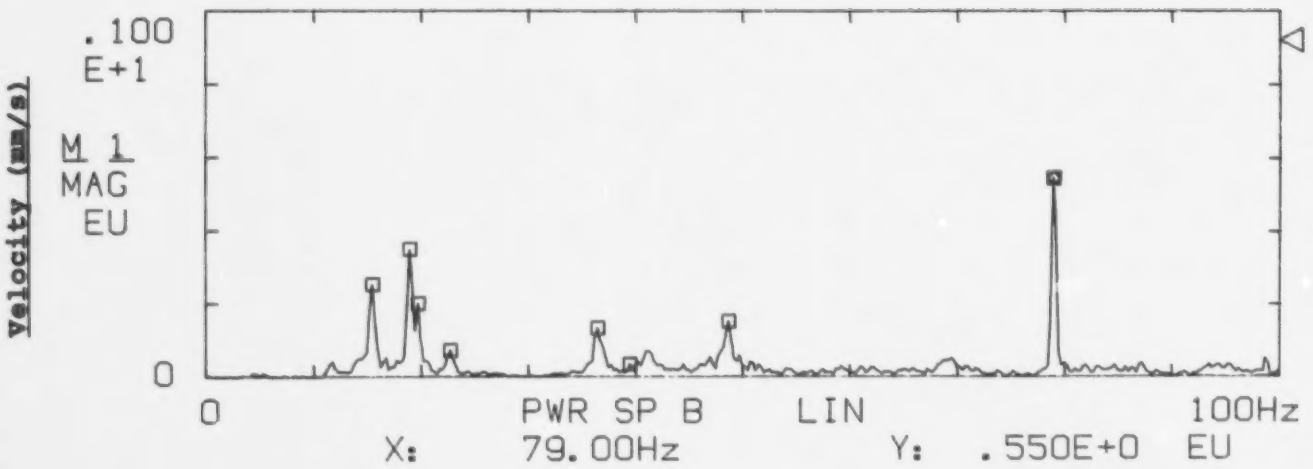


FIGURE 73
ECI RECOVERY PUMPSET #24 -PUMP STOOL VELOCITY
(E-W DIRECTION) WITHOUT ABSORBER

00:25

BRUCE GSA ECI REC P#24 PUMP STOOL N-S NO ABS VEL 02:52
100Hz A: AC/ 50V B: AC/ 50V S. SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	16.25Hz	.300E+0	EU
2	20.00	.134E+0	
3	28.75	.147E+0	
4	70.00	.267E+0	
5	102.50	.320E+0	
6	120.00	.187E+0	
7	158.75	.178E+0	
8	237.50	.186E+0	
9			
10			

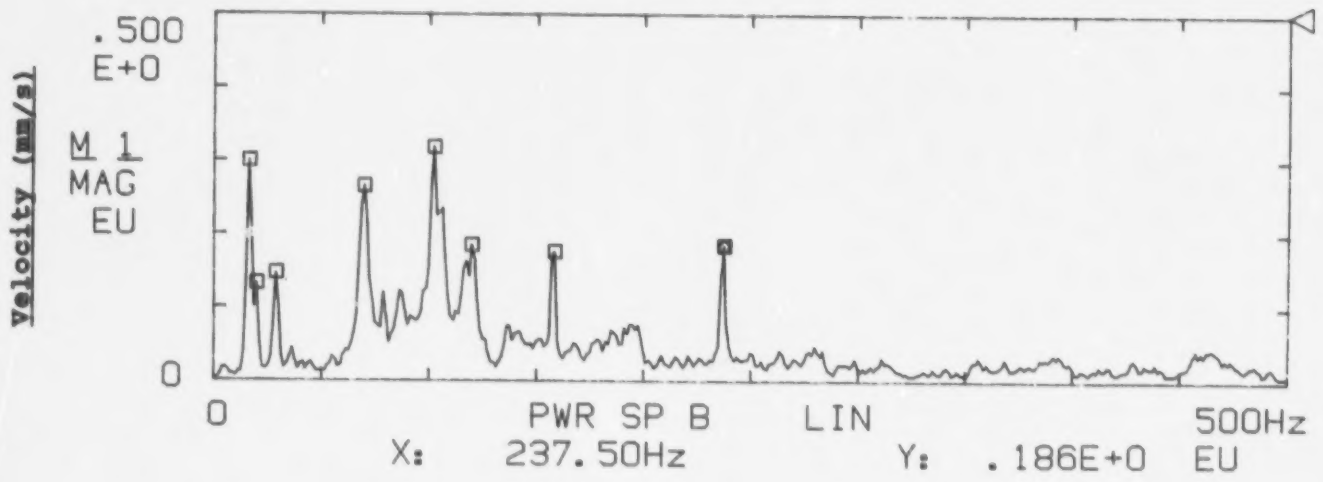


FIGURE 74
ECI RECOVERY PUMPSET #24 -PUMP STOOL VELOCITY (N-S DIRECTION) WITHOUT ABSORBER

00:21

87-301

BRUCE GSA ECI REC P#24 PUMP STOOL AXI NO ABS VEL 02:55
200Hz A: AC/0.5V B: AC/0.1V S. SUM 0/32 DUAL 1k

	PWR SPECTRUM	ChB	
1	15.50Hz	.730E-1	EU
2	19.75	.142E+0	
3	44.00	.278E+0	
4	56.50	.206E+0	
5	79.00	.271E+0	
6			
7			
8			
9			
10			

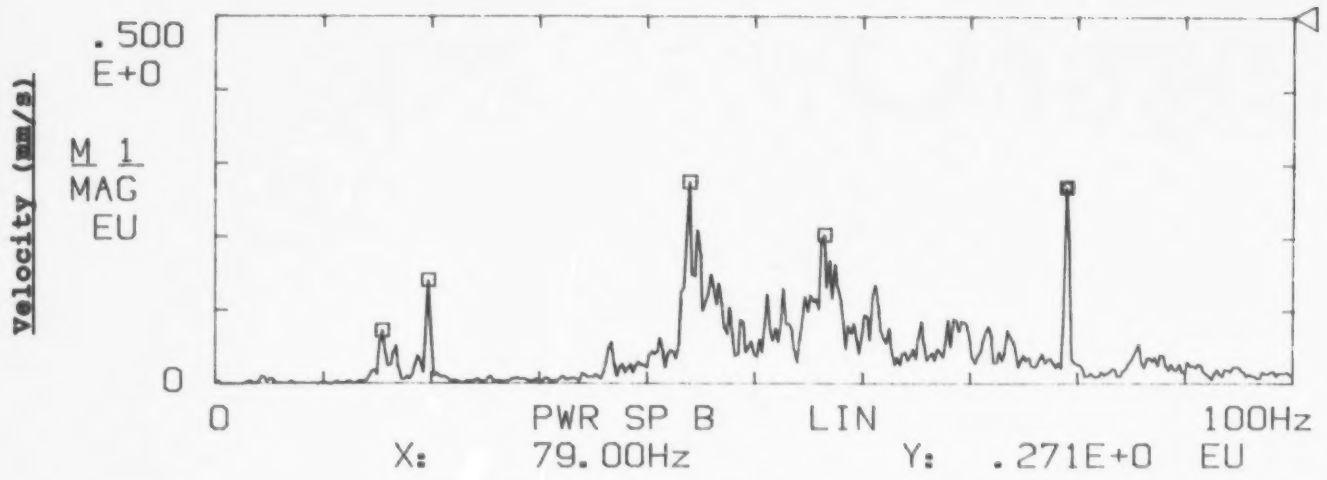


FIGURE 75
ECI RECOVERY PUMPSET #24 -PUMP STOOL VELOCITY
(AXIAL DIRECTION) WITHOUT ABSORBER

00:06

BRUCE GSA ECI REC P#24 MOTOR TOP E-W W/ABS VEL 06:50
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	16.25Hz	.474E+0	EU
2	19.75	.115E+0	
3	22.50	.156E+1	
4	36.75	.470E+0	
5	41.50	.501E+0	
6	79.00	.149E+0	
7			
8			
9			
10			

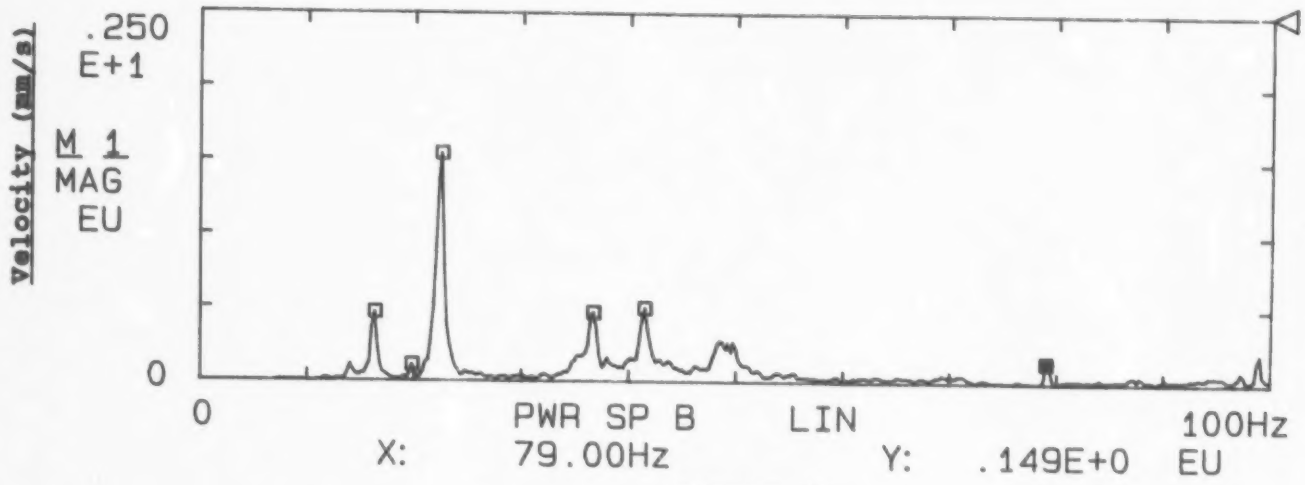


FIGURE 76
ECI RECOVERY PUMPSET #24 -TOP OF MOTOR CASING VELOCITY (E-W DIRECTION) WITH ABSORBER

16:33

87-301

BRUCE GSA ECI REC P#24 MOTOR TOP N-S W/ABS VEL 06:51
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	16.50Hz	.871E+0	EU
2	19.75	.120E+1	
3	26.00	.995E+0	
4	39.50	.358E+0	
5	69.50	.182E+0	
6	79.00	.891E-1	
7			
8			
9			
10			

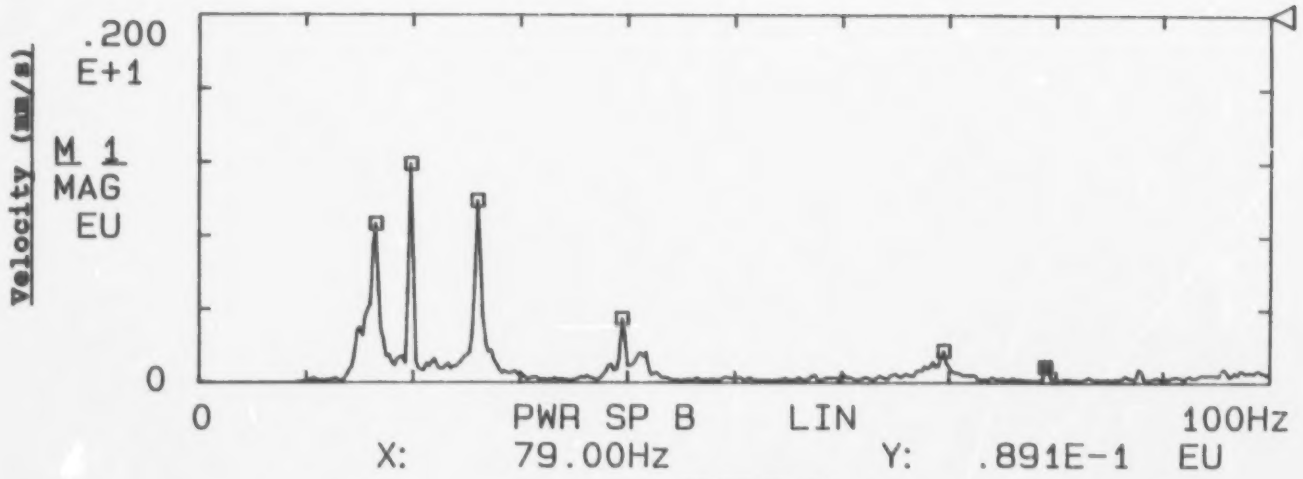


FIGURE 77
ECI RECOVERY PUMPSET #24 -TOP OF MOTOR CASING VELOCITY (N-S DIRECTION) WITH ABSORBER

16:36

87-301

BRUCE GSA ECI REC P#24 MOTOR TOP AXI W/ABS VEL 06:53
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	20.00Hz	.129E+0	EU
2	43.75	.853E+0	
3	51.25	.457E+0	
4	78.75	.807E+0	
5	157.50	.420E+0	
6	280.00	.125E+0	
7			
8			
9			
10			

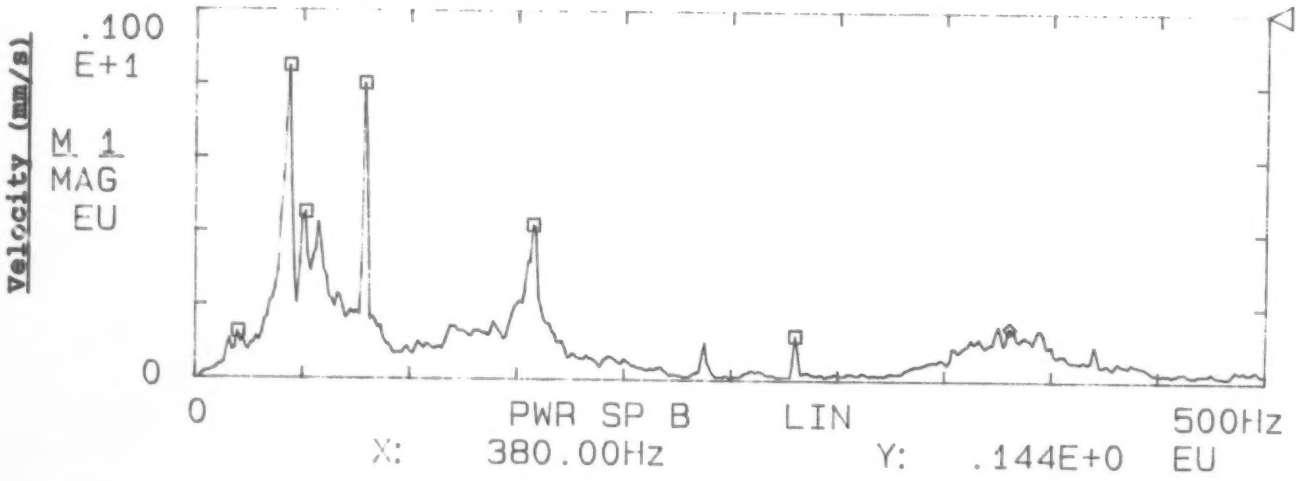


FIGURE 78
ECI RECOVERY PUMPSET #24 -TOP OF MOTOR CASING VELOCITY (AXIAL DIRECTION) WITH ABSORBER

16:41

BRUCE GSA ECI REC P#24 MOTOR BOT E-W W/ABS VEL 06:58
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	16.25Hz	.199E+0	EU
2	19.75	.415E+0	
3	22.50	.120E+1	
4	79.00	.260E+0	
5			
6			
7			
8			
9			
10			

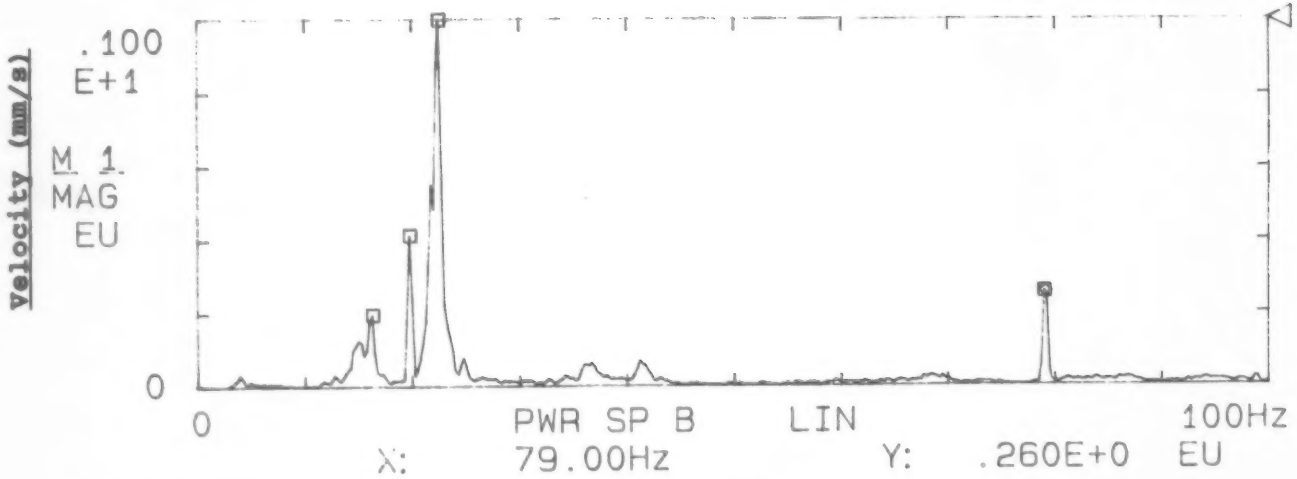


FIGURE 79
ECI RECOVERY PUMPSET #24 -BOTTOM OF MOTOR CASING VELOCITY (E-W DIRECTION) WITH ABSORBER

16:43

BRUCE GSA ECI REC P#24 MOTOR BOT N-S W/ABS VEL 07:00
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	16.50Hz	.833E+0	EU
2	20.00	.471E+0	
3	26.00	.416E+0	
4	41.50	.201E+0	
5	158.00	.343E+0	
6			
7			
8			
9			
10			

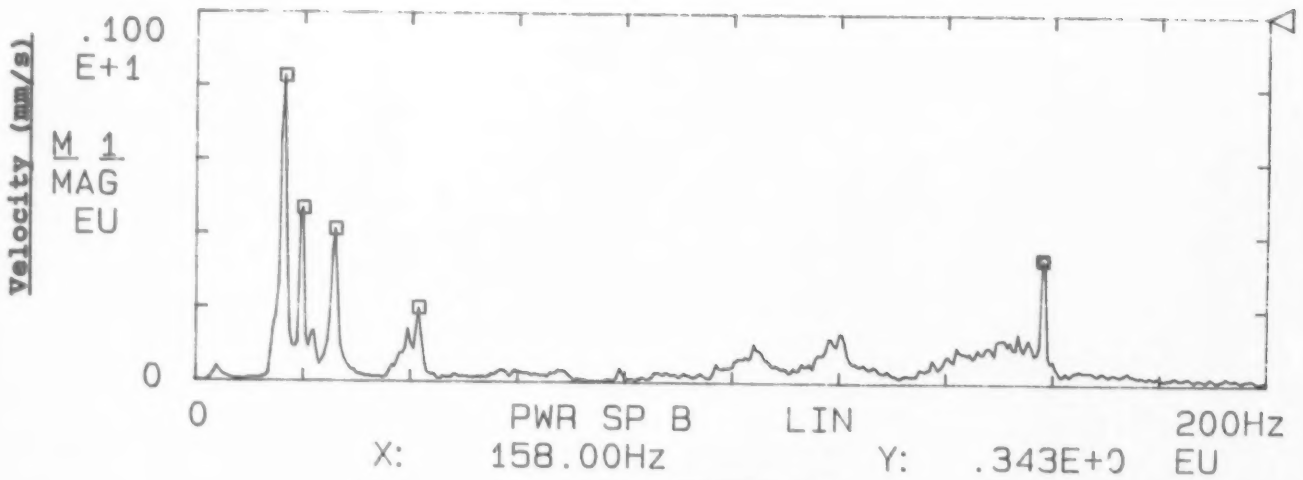


FIGURE 80
ECI RECOVERY PUMPSET #24 -BOTTOM OF MOTOR CASING VELOCITY (N-S DIRECTION) WITH ABSORBER

BRUCE GSA ECI REC P#24 PUMP STOOL E-W W/ABS VEL 07:07
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	15.25Hz	.265E+0	EU
2	19.75	.437E+0	
3	22.50	.865E+0	
4	79.00	.581E+0	
5			
6			
7			
8			
9			
10			

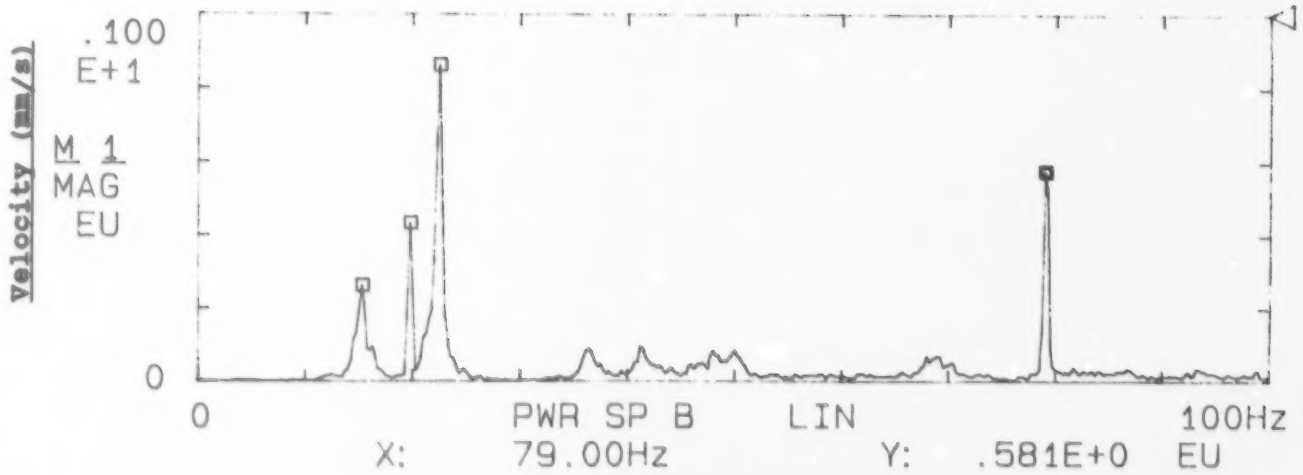


FIGURE 81
ECI RECOVERY PUMPSET #24 -PUMP STOOL VELOCITY (E-W DIRECTION) WITH ABSORBER

00:08

87-301

BRUCE GSA ECI REC P#24 PUMP STOOL N-S W,'ABS VEL 07:05
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/32 DUAL 1k

	PWR SPECTRUM	ChB	
1	16.25Hz	.313E+0	EU
2	19.75	.147E+0	
3	25.75	.120E+0	
4	39.50	.335E-1	
5	68.75	.146E+0	
6	79.00	.973E-1	
7			
8			
9			
10			

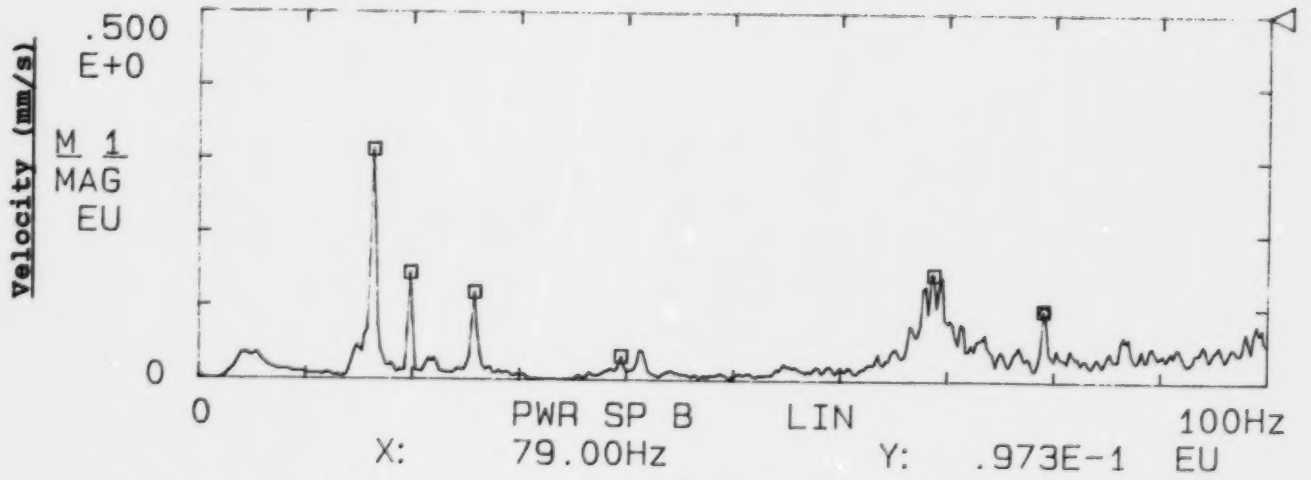


FIGURE 82
ECI RECOVERY PUMPSET #24 -PUMP STOOL VELOCITY (N-S DIRECTION) WITH ABSORBER

00:04

BRUCE GSA ECI REC P#24 PUMP STOOL AXI W/ABS VEL 07:08
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/16 DUAL 1k

	PWR SPECTRUM	ChB	
1	15.25Hz	.933E-1	EU
2	16.25	.843E-1	
3	19.75	.146E-1	
4	22.25	.121E+0	
5	43.50	.250E+0	
6	55.75	.174E+0	
7	79.00	.277E+0	
8			
9			
10			

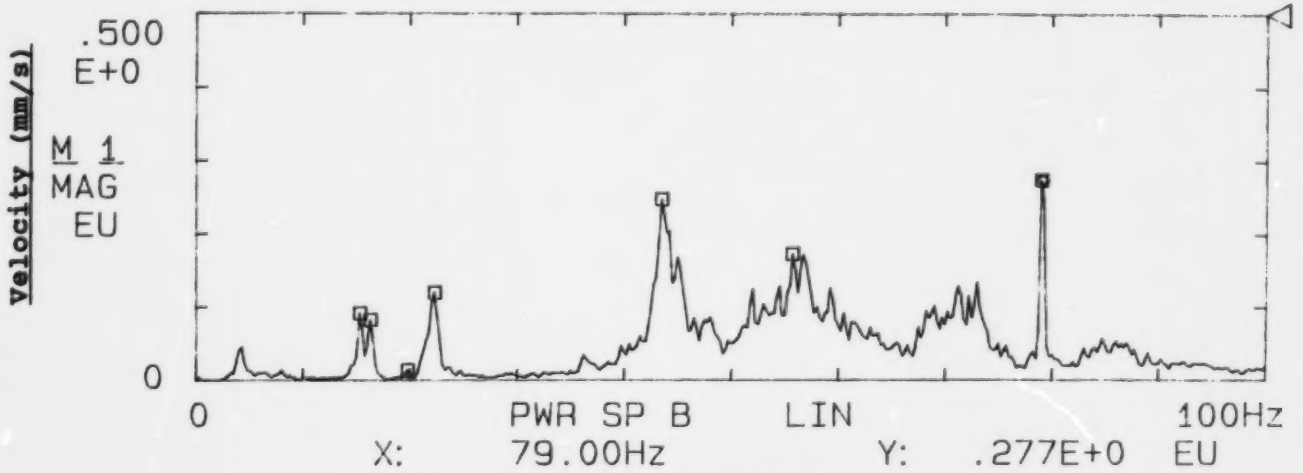


FIGURE 83
ECI RECOVERY PUMPSET #24 -PUMP STOOL VELOCITY (AXIAL DIRECTION) WITH ABSORBER

00: 10

87-301

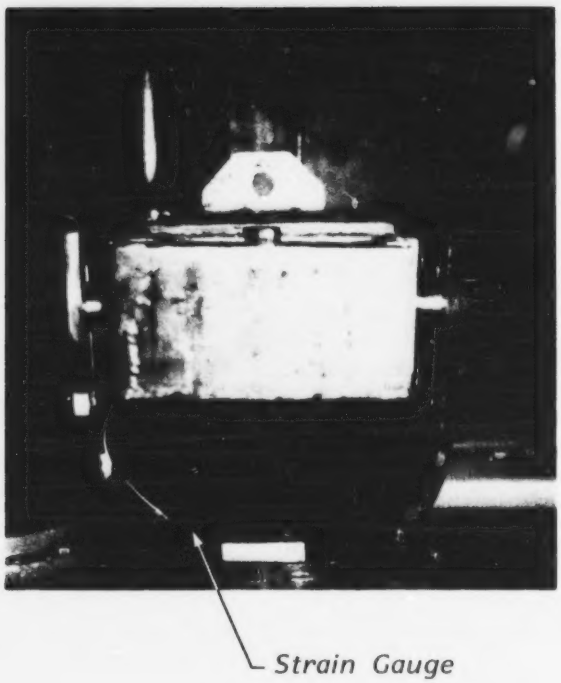


FIGURE 84
LOCATION OF STRAIN GAUGE

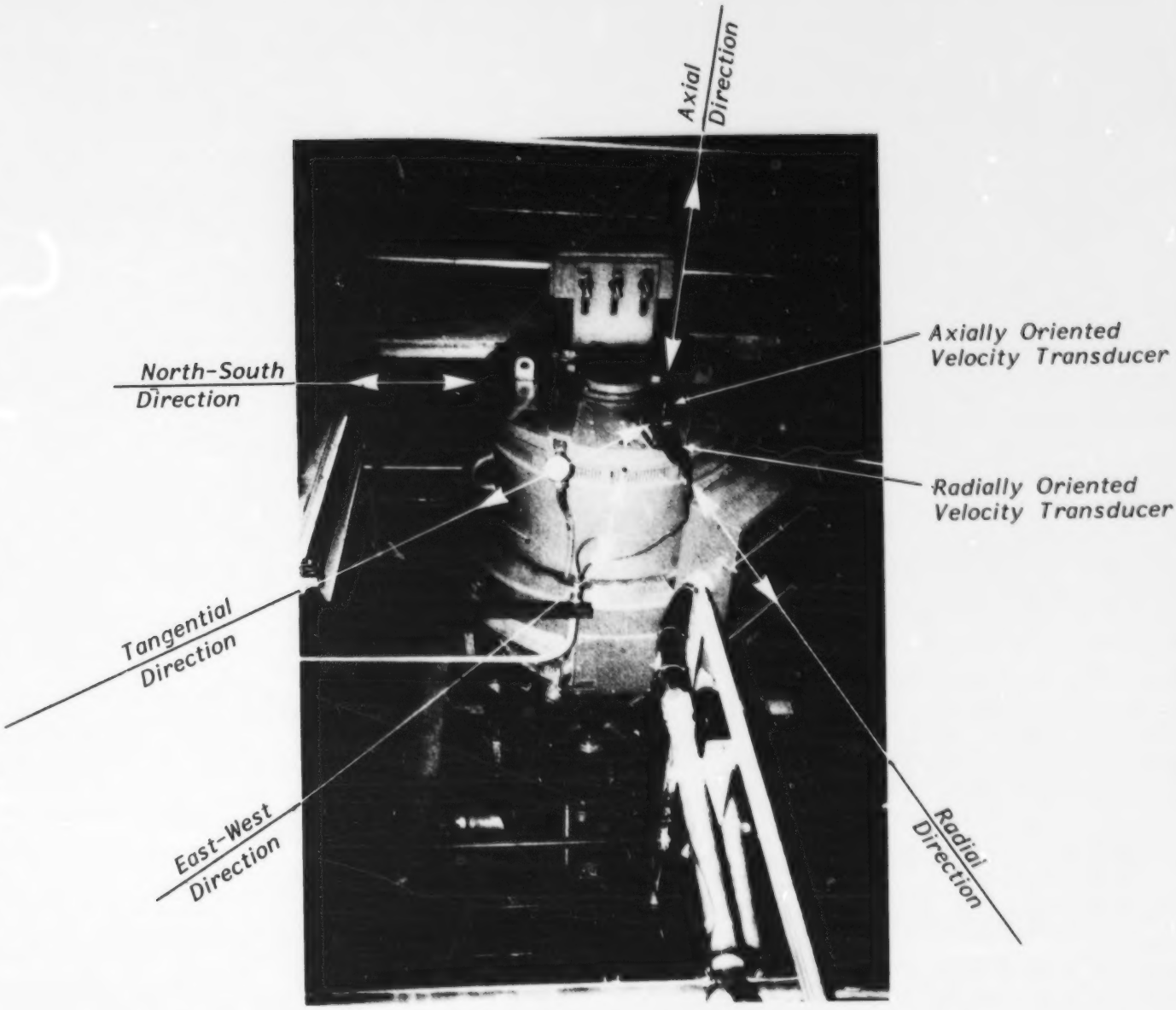


FIGURE 85
VELOCITY TRANSDUCER LOCATIONS

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APPENDIX A

UNDAMPED DYNAMIC VIBRATION ABSORBER THEORETICAL FORMULATION

APPENDIX A

UNDAMPED DYNAMIC VIBRATION ABSORBER THEORETICAL FORMULATION

The absorber spring is shown in Figure A-1. In the following analysis, it was assumed that the spring straight portion between the bolts is inactive. Thus the model used for the theoretical formulation is shown in Figure A-2. The variables used in the formulation below are described at the end of the appendix.

The absorber spring is subdivided into curved and straight beam sections.

Curved Beam Loads

Shear

$$V = P \cos \theta$$
$$N = P \sin \theta$$
$$M_x = P (Z + R \sin \theta)$$

Straight Beam Loads

Shear

$$V = P$$

Moment

$$M_x = P.Z$$

CURVED BEAM DEFLECTION USING CASTIGLIANO'S THEOREM/1,2,3/

STRAIN ENERGY FOR CURVED BEAM

Total strain energy U for the curved beam (1/2 circle) is:

$$U_c = \underset{(A)}{\int_0^{\pi} \frac{k\,V^2 R}{2\,AG}\,d\theta} + \underset{(B)}{\int_0^{\pi} \frac{N^2 R}{2AE}\,d\theta} + \underset{(C)}{\int_0^{\pi} \frac{A_m M_x^2}{2\,A(R A_m - A)E}\,d\theta}$$

A - strain energy due to shear (V)

B - strain energy due to normal load (N)

C - strain energy due to bending moment (M_x)

DEFLECTION DUE TO SHEAR

$$\delta_{cs} = \frac{\partial U_{cs}}{\partial P} = \frac{\partial}{\partial P} \int_0^{\pi} \frac{k\,V^2 R}{2\,AG}\,d\theta$$

$$V = P \cos\theta$$

$$= \frac{\partial}{\partial P} \int_0^{\pi} \frac{k\,P^2 \cos^2\theta\,R\,d\theta}{2\,AG}$$

$$= \frac{k\,RP}{AG} \int_0^{\pi} \cos^2\theta\,d\theta$$

$$= \frac{k\,RP}{2AG} \left[\frac{1}{4}\sin 2\theta + \frac{\theta}{2}\right]_0^{\pi} \qquad /4/$$

$$= \frac{k\,RP}{2AG} \left[\frac{1}{4}\sin 2\pi + \frac{\pi}{2} - \frac{1}{4}\sin 0 - \frac{0}{2}\right]$$

$$\delta_{cs} = \frac{\pi\,k\,RP}{4\,AG}$$

DEFLECTION DUE TO NORMAL LOAD

$$\delta_{cn} = \frac{\partial U_{cs}}{\partial P} = \frac{\partial}{\partial P} \int_0^{\pi} \frac{N^2 R}{2AE} \, d\theta$$

$$N = P \sin\theta$$

$$= \frac{\partial}{\partial P} \int_0^{\pi} \frac{P^2 \sin^2\theta \, R \, d\theta}{2AE}$$

$$= \frac{PR}{AE} \int_0^{\pi} \sin^2\theta \, d\theta$$

$$= \frac{PR}{AE} \left[-\frac{1}{4} \sin 2\theta + \frac{1}{2}\theta \right]_0^{\pi} \qquad /4/$$

$$= \frac{PR}{AE} \left[-\frac{1}{4} \sin 2\pi + \frac{1}{2}\pi + \frac{1}{4} \sin\theta - \frac{1}{2}(0) \right]$$

$$\delta_{cn} = \frac{\pi PR}{2AE}$$

DEFLECTION DUE TO MOMENT

$$\delta_{cm} = \frac{\partial U_{cm}}{\partial P} = \frac{\partial}{\partial P}\int_0^{\pi} \frac{A_m M_x^2}{2A[R A_m - A]E}\, d\theta$$

$$M_x = P[Z + R \sin\theta]$$

$$= \frac{\partial}{\partial P}\int_0^{\pi} \frac{A_m [P(Z+R\sin\theta)]^2\, d\theta}{2A(R A_m - A)E}$$

$$= \frac{A_m P}{A[R A_m - A]E}\int_0^{\pi} [Z^2 + 2Z R \sin\theta + R^2\sin^2\theta]\, d\theta$$

$$= \frac{A_m P}{A[R A_m - A]E}\left[Z^2\theta\Big|_0^{\pi} + 2ZR[-\cos\theta]\Big|_0^{\pi} + R^2\left[-\frac{1}{4}\sin 2\theta + \frac{1}{2}\theta\right]\Big|_0^{\pi}\right]$$

$$= \frac{A_m P}{A[R A_m - A]E}\left[Z^2(\pi) - Z^2(0) + 2ZR[-\cos\pi + \cos 0] + R^2\left[-\frac{1}{4}\sin 2\pi + \frac{1}{2}\pi + \frac{1}{4}\sin 2(0) - \frac{1}{2}(0)\right]\right]$$

$$\delta_{cm} = \frac{A_m P}{A[R A_m - A]E}\left[Z^2(\pi) + 4ZR = \frac{1}{2}\pi R^2\right]$$

STRAIN ENERGY FOR STRAIGHT BEAM

(A) (B)

$$U_s = \int_0^z \frac{M_x^2}{2EI_x}\, d\,z + \int_0^z \frac{k\,V^2}{2\,GA}\, d\,z$$

A = strain energy due to moment

B = strain energy due to shear

DEFLECTION DUE TO MOMENT

$$\delta_{sm} = \frac{\partial U_m}{\partial P} = \frac{\partial}{\partial P} \int_0^z \frac{M_x^2 dz}{2\,EI_x}$$

$$M_x = Pz$$

$$= \frac{\partial}{\partial P} \int_0^z \frac{P^2 z^2 dz}{2EI_x}$$

For 2 straight sections

$$= \frac{\partial}{\partial P} \int_0^z \frac{P^2 z^2 dz}{EI_x}$$

$$= \frac{2P}{EI_x} \int_0^z z^2 dz$$

$$\delta_{sm} = \frac{2\,Pz^3}{3\,EI_x}$$

DEFLECTION DUE TO SHEAR

$$\delta_{ss} = \frac{\partial U_s}{\partial P} = \frac{\partial}{\partial P} \int_0^z \frac{k\ V^2}{2\ GA}\ dz$$

$$V = P$$

$$= \frac{\partial}{\partial P} \int_0^z \frac{KP^2 dz}{2GA}$$

For 2 straight sections

$$= \frac{\partial}{\partial P} \int_0^z \frac{KP^2 dz}{GA}$$

$$= \frac{2PK}{GA} \int_0^z dz$$

$$\delta_{ss} = \frac{2PKz}{GA}$$

TOTAL ABSORBER SPRING DEFLECTION

$$\delta_T = \frac{\pi\, kRP}{4AG} + \frac{\pi PR}{2AE} + \frac{A_m P}{A[R A_m - A]E}\left[Z^2(\pi) + 4ZR + \frac{1}{2}\pi R^2\right]$$

$$+ \frac{2}{3}\frac{PZ^2}{EI_x} + \frac{2\, PKZ}{GA}$$

ABSORBER SPRING STIFFNESS

$$K = \frac{P}{\delta_T}$$

ABSORBER TUNED FREQUENCY

$$\omega_n = \frac{1}{2\pi}\sqrt{\frac{K}{M}}$$

MAXIMUM ABSORBER SPRING STRESS

The maximum circumferential stress occurs on the inner fibre of the curved beam section at $\vartheta = 90°$

$$\sigma_{\theta\theta} = \frac{N}{A} + \frac{M_x\,(A - rA_m)}{A\, r(R A_m - A)} \qquad /3/$$

Figure A-3 shows the spring stiffness for three spring support conditions. In its final assembly (ie, with mass attached) the ECI Recovery Pumpset motor absorber spring support condition can be represented by Figure A-3 (c).

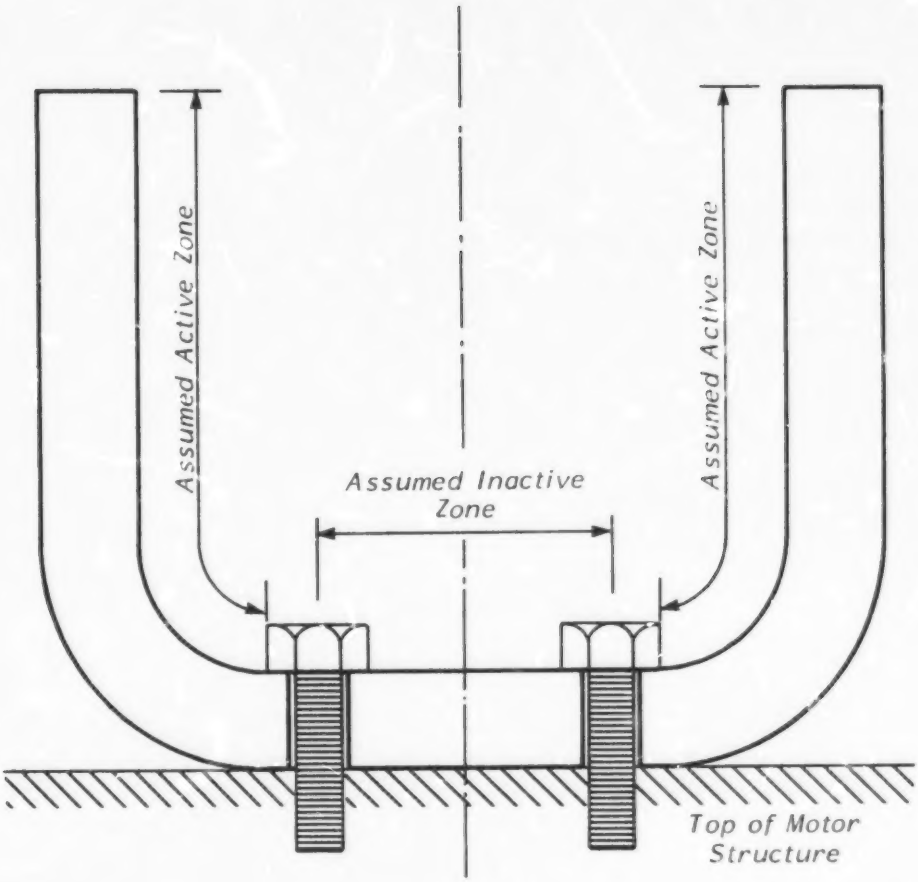

FIGURE A-1
ABSORBER SPRING

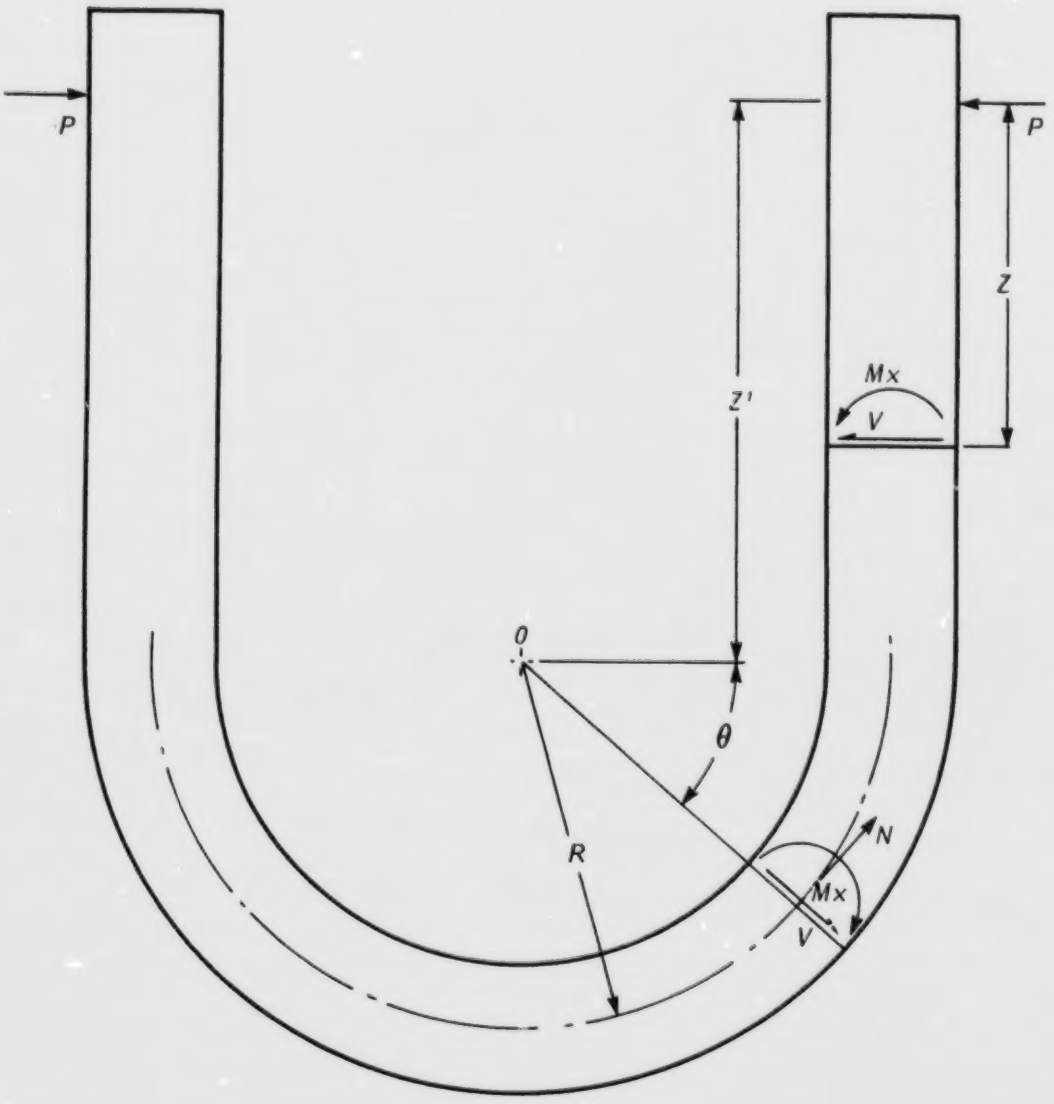

FIGURE A-2
ABSORBER SPRING MODEL

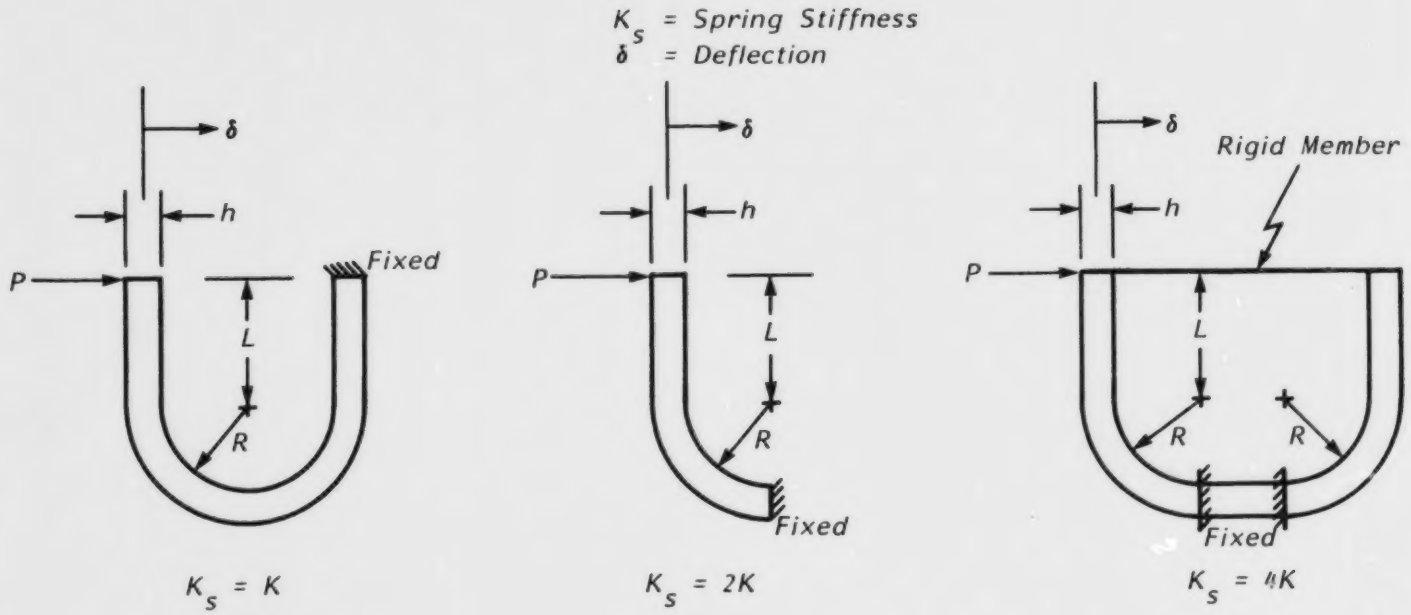

FIGURE A-3
STIFFNESS FOR VARIOUS SPRING CONFIGURATIONS

NOMENCLATURE

	Units
A = Cross-Sectional area	m^2
$A_m = \int \frac{dA}{r}$	m
E = Young's modulus of elasticity	N/m^2
G = shear modulus of elasticity	N/m^2
K = absorber spring stiffness	N/m
k = correction coefficient for strain energy due to shear	
M = absorber mass	kg
M_x = moment	N-m
N_f = absorber spring fatigue life	cycles
P = absorber mass load	N
R = neutral radius of curved beam	m
r = radius to beam element	m
U_c = strain energy of the curved beam section	N-m
U_s = strain energy of the straight beam section	N-m
V = shear load	N
δ_{cm} = curved beam section deflection due to the moment	m
δ_{cn} = curved beam section deflection due to the normal load	m
δ_{cs} = curved beam section deflection due to shear	m
δ_{sm} = straight beam section deflection due to the moment	m
δ_{ss} = straight beam section deflection due to shear	m
δ_T = absorber spring total deflection	m
$\sigma_{\theta\theta}$ = circumferential stress on the curved beam section	N/m^2
ω_η = absorber tuned natural frequency	rad/s

APPENDIX B

FATIGUE LIFE ANALYSIS OF ABSORBER SPRING

APPENDIX B

FATIGUE LIFE ANALYSIS OF ABSORBER SPRING

1. Calculation of maximum tensile strain based on the measured absorber mass displacements (sinusoidal).

The maximum dynamic absorber mass loading is:

$$P = m \ddot{x}$$

$$= m \frac{D}{2} (2\pi f)^2$$

where m = absorber mass

$\ddot{x}$ = acceleration of absorber mass

D = maximum displacement (p-p) of absorber mass

f = frequency

For the curved beam shown in Figure B-1, the maximum tensile stress due to force P will be at point C and is given by:

$$\sigma_c = \frac{M (R - r_i)}{A (\bar{r} - R) r_i} + \frac{P}{A}$$

Also:

$$M = Pb_{max} \quad ; \quad \sigma_c = E \varepsilon_c \quad ; \quad R = \frac{h}{\ln\left(\frac{r_o}{r_i}\right)}$$

where

M = bending moment
r_i = radius of curvature of inner fibre
$\bar{r}$ = radius of curvature of centroidal axis
R = radius of curvature of neutral axis
A = cross-sectional area of absorber spring
P = force
h = absorber spring thickness
E = Youngs modulus of elasticity
ε_c = maximum strain at point C.

Hence:

$$\varepsilon_c = \frac{P}{AE}\left(\frac{b_{max}(R - r_i)}{(\bar{r} - R)\, r_i} + 1\right)$$

° Sample calculation for Pumpset #23 absorber

r_o = 17.018 cm (6.7 in) $\quad$ h = 1.778 cm (0.7 in)

r_i = 15.24 cm (6 in) $\quad$ $\bar{r}$ = 16.129 cm (6.35 in)

b_{max} = 34.61 cm (13.625 in)

A = 30.48 x 1.778 = 54.19 cm^2

D = 400 μm (peak-peak)

m = 263 kg (580 lbs)

E = 2 x 10^{11} Pa (for SPS 245)

f = 19.75 Hz (operating speed)

° $P = \frac{mD}{2}(2\pi f)^2 = (263)\left(\frac{400 \times 10^{-6}}{2}\right)(2\pi(19.75))^2$

= 810 N

° $R = \frac{h}{\ln\left(\frac{r_o}{r_i}\right)} = \frac{1.778}{\ln\left(\frac{17.018}{15.24}\right)}$ = 16.113 cm (6.343 in)

° $\varepsilon_c = \frac{810}{(54.19 \times 10^{-4})(2 \times 10^{11})}\left[\frac{(0.3461)\,(0.1611 - 0.1524)}{(0.16129 - 0.16113)\,(0.1524)} + 1\right]$

$= 93 \times 10^{-6}\ \frac{mm}{mm} = 93\ \mu\varepsilon$

In a similar manner, the maximum tensile strain on the other three absorber springs can be calculated. These strains are summarized in Table B-1.

r_o = Radius of Curvature of the Outer Fibre
r_i = Radius of Curvature of the Inner Fibre
R = Radius of Curvature of Neutral Axis
$\bar{r}$ = Radius of Curvature of Centroidal Axis

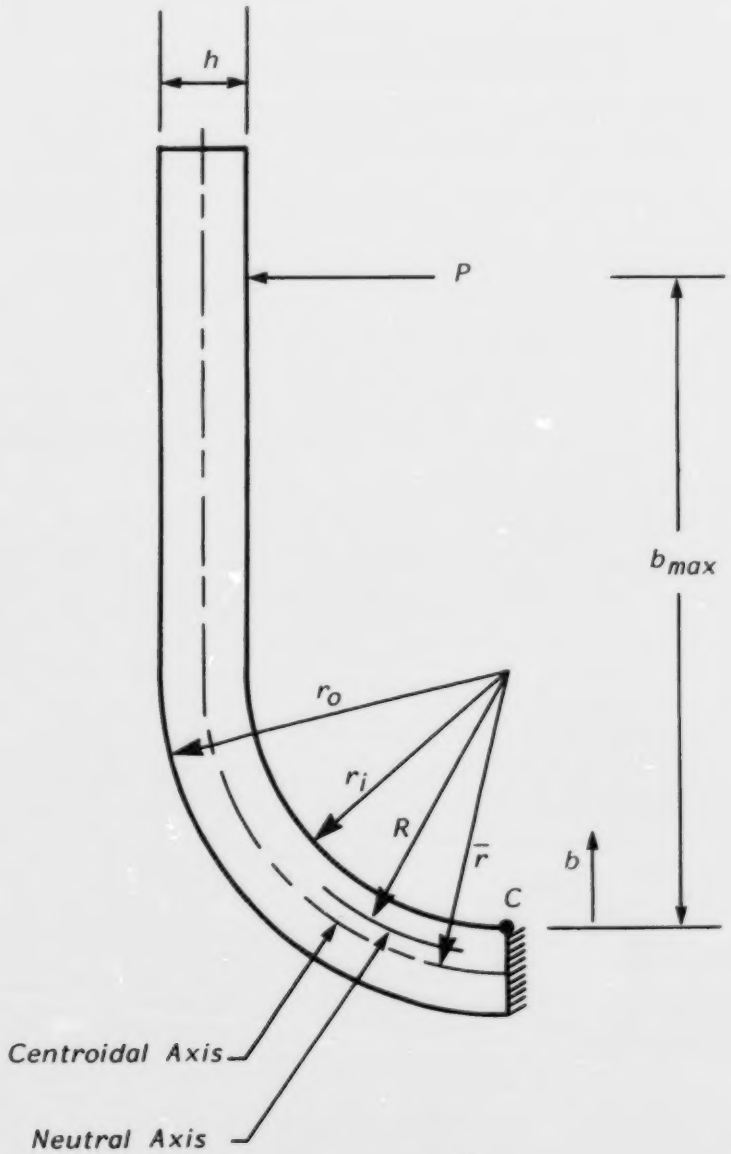

FIGURE B-1
CURVED BEAM

TABLE B-1

MAXIMUM OVERALL DISPLACEMENT LEVELS MEASURED ON THE ABSORBER MASS AND CORRESPONDING CALCULATED MAXIMUM TENSILE STRAIN IN ABSORBER SPRING

Pumpset No	Maximum Overall Displacement Level Measured on Absorber Mass (μm p-p)	Calculated Maximum Tensile Strain in Absorber Spring ($\mu\varepsilon$ 0-p)
P #21	318	74
P #22	110	26
P #23	400	93
P #24	225	52

2. Calculation of fatigue life

The following fatigue life calculation is carried out for Pumpset #23 absorber spring since this is the worst case (ie, maximum strain).

Assuming an overall safety factor of 2, the maximum tensile strain used for the fatigue life calculation is:

$$\varepsilon = 2 \times 93 \times 10^{-6} \frac{m}{m} = 186 \times 10^{-6} \frac{m}{m}$$

Fatigue life equation is:

$$N_f = \frac{1}{2}\left(\frac{\varepsilon E}{\sigma_f}\right)^{1/b}$$

where N_f = fatigue life (cycles)

σ_f = fatigue strength coefficient

b = fatigue strength exponent

For SPS 245

Assumed σ_f = 1825 MPa/5/
Assumed b = -0.08 /5/

Estimated fatigue life of the spring is:

$$N_f = \frac{1}{2}\left(\frac{186\times10^{-6}\ m/m \times 2 \times 10^{11}\ N/m^2}{1825 \times 10^{6}\ N/m^2}\right)^{\frac{-1}{0.08}}$$

$$= 6.807 \times 10^{20} \text{ cycles}$$

Assuming continuous pumpset operation, the number of cycles that the absorber spring would undergo in one year is:

$$N_y = 19.75 \frac{\text{cycles}}{s} \times \frac{3600\ s}{hr} \times \frac{24\ hr}{day} \times \frac{365\ day}{year}$$

$$= 6.228 \times 10^{8} \text{ cycles/year}$$

Therefore the estimated theoretical fatigue life of the absorber spring is:

$$\frac{N_f}{N_y} = \frac{6.807 \times 10^{20} \text{ cycles}}{6.228 \times 10^{8} \text{ cycles/year}} = 1.093 \times 10^{12} \text{ years}$$